PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark
Office, PCT
2011 South Clark Place Room
CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 29 January 2001 (29.01.01)	
International application No. PCT/CA00/00834	**Applicant's or agent's file reference** CF/12657.13
International filing date (day/month/year) 14 July 2000 (14.07.00)	**Priority date** (day/month/year) 14 July 1999 (14.07.99)
Applicant COULOMBE, Alain et al	

1. The designated Office is hereby notified of its election made:

   [X] in the demand filed with the International Preliminary Examining Authority on:

   13 December 2000 (13.12.00)

   [ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was
   [ ] was not

   made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland Facsimile No.: (41-22) 740.14.35	Authorized officer A. Karkachi Telephone No.: (41-22) 338.83.38

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 00/00834

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01B11/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 182 469 A (NEW YORK INST TECHN) 28 May 1986 (1986-05-28) page 4, line 1 -page 6, line 4 page 22, line 2 -page 27; figures 7-9	1-4, 9-13,16
X	WO 98 55826 A (ELECTRONIC PACKAGING SERVICES ;WANG YINYAN (US)) 10 December 1998 (1998-12-10) the whole document	1-13,16, 17
X	GB 2 204 397 A (EASTMAN KODAK CO) 9 November 1988 (1988-11-09) page 9 -page 11	1,2,4,16

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 October 2000	19/10/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Ramboer, P

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	WO 88 02847 A (EASTMAN KODAK CO) 21 April 1988 (1988-04-21) page 1, line 28 -page 2, line 28; figure 1 page 7, line 25 - line 36 page 19, line 30 -page 20, line 15 -----	1,15

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/CA 00/00834

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0182469 A	28-05-1986	US 4641972 A	10-02-1987
		US 4657394 A	14-04-1987
		CA 1261656 A	26-09-1989
		DE 3580740 D	10-01-1991
		JP 1675753 C	26-06-1992
		JP 3038524 B	11-06-1991
		JP 61076906 A	19-04-1986
WO 9855826 A	10-12-1998	AU 7720798 A	21-12-1998
		US 5969819 A	19-10-1999
GB 2204397 A	09-11-1988	US 5085502 A	04-02-1992
		DE 3813692 A	17-11-1988
		FR 2614691 A	04-11-1988
WO 8802847 A	21-04-1988	US 4794550 A	27-12-1988
		EP 0327567 A	16-08-1989
		JP 2500217 T	25-01-1990

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e) projecting the grid on the object; the grid being located at the first position;

f) taking with the camera an image of the object illuminated by the projected grid; the image of the object having intensity values for each pixel position;

g) repeating steps e) and f) at least two times with the grid being located at the two different positions to yield at least three intensity values for each pixel;

h) computing the object phase for each pixel position using the at least three object intensity values for the corresponding pixel;

i) computing the difference of height between the object and the reference object for each pixel using the reference object phase and the object phase for the corresponding pixel; and

j) using the difference of heights between the object and the reference object for each pixel to determine the relief of the object.

According to a another aspect of the present invention, there is provided a method for measuring the height of a module including at least one object mounted on a generally plane substrate using a camera provided with an array of pixels, the method comprising:

a) projecting a grid onto the module; the grid being located at a first position relative to the camera and to the module;

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AMENDED SHEET

b) taking, with the camera, an image of the module illuminated by the projected grid; the image of the module having intensity values for each pixel;

c) repeating steps a) and b) at least two times with the grid being located at two different known positions relative to the camera and to the module to yield at least three intensity values for each pixel;

d) computing the module phase for each pixel using the at least three module intensity values for the corresponding pixel;

e) computing a complementary phase of the substrate by using the at least three intensity values from pixels on the image of the module not corresponding to the at least one object;

f) computing the height of the at least one object for each pixel using the complementary phase of the substrate and the module phase for the corresponding pixel;

g) projecting the grid onto a reference plane; the grid being located at the first position;

h) taking with the camera an image of the reference plane illuminated by the projected grid; the image of the reference plane having intensity values for each pixel position;

i) repeating steps g) and h) at least two times with the grid being located at the two different positions to yield at least three intensity values for each pixel;

j) computing the reference plane phase for each pixel position using the at least three reference plane intensity values for the corresponding pixel;

k) computing the height of the substrate for each pixel using the complementary plane phase of the substrate and the reference plane phase for the corresponding pixel; and

computing the height of the module by adding the height of the substrate and the height of the at least one object.

According to another aspect of the present invention, there is also provided a system for measuring the relief of an object, the system comprising:

a grid projecting assembly; the grid projecting assembly including a grid, an illuminating assembly that includes a light source to be projected through the grid onto the object and a projector to project the grid onto the object; the grid being mounted to a support;

an image acquisition apparatus including a camera provided with an array of pixels;

a computer configured for

a) positioning the grid relative to the object and to the image acquisition apparatus;

b) receiving from the image acquisition apparatus at least three images of the projected grid onto the object and at least three images of the projected grid onto a reference object; each of the images of the projected grid onto the object corresponding to a different known position of the grid; each of the images of the projected grid onto the reference object corresponding to one of the known positions of the grid;

c) computing the reference object phase for each pixel using the at least three reference object intensity values for the

corresponding pixel;

d) computing the object phase for each pixel using the at least three object intensity values for the corresponding pixel; and

e) computing the difference of height between the object and the reference object for each pixel using the reference object phase and the object phase for the corresponding pixel.

Other objects, advantages and features of the present invention will become more apparent upon reading the following non-restrictive description of preferred embodiments thereof, given by way of example only, with reference to the accompanying drawing

BRIEF DESCRIPTION OF THE DRAWINGS

In the appended drawings:

Figure 1 is a schematic view of a system for inspecting the surface of an object according to an embodiment of the present invention;

Figure 2 is a schematic view of both the image acquisition apparatus and the grid projection assembly of Figure 1;

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WHAT IS CLAIMED IS:

1. A method for measuring the relief of an object using a camera provided with an array of pixels, said method comprising:

a) projecting a grid on a reference object; the grid being located at a first position relative to the camera and to the reference object;

b) taking, with the camera, an image of the reference object illuminated by said projected grid; said image of the reference object having intensity values for each pixel;

c) repeating steps a) and b) at least two times with the grid being located at two different known positions relative to the camera and to the reference object to yield at least three intensity values for each pixel;

d) computing the reference object phase for each pixel using the at least three reference object intensity values for the corresponding pixel;

e) projecting the grid on the object; the grid being located at said first position;

f) taking with the camera an image of the object illuminated by said projected grid; said image of the object having intensity values for each pixel position;

g) repeating steps e) and f) at least two times with the grid being located at said two different positions to yield at least three intensity values for each pixel;

h) computing the object phase for each pixel position using the at least three object intensity values for the corresponding pixel;

i) computing the difference of height between the object and the reference object for each pixel using said reference object phase and said object phase for the corresponding pixel; and

j) using said difference of heights between the object and the reference object for each said pixel to determine the relief of the object.

2. A method as recited in claim 1, wherein, in at least one of steps d) and h), the phase $\Delta\Phi$ is computed for each pixel by solving the following system of equations:

$$I_n = A + B \cdot \cos(\Delta\Phi + \Delta\varphi_n)$$

where I_n represent the at least three intensity values, A and B are known coefficients and $\Delta\varphi_n$ are phase variations caused by the different locations of the grid.

3. A method as recited in claim 1, wherein, in step c), steps a) and b) are repeated more than two times with the grid being located at more than two different known positions relative to the camera and to the reference object to yield more than three intensity values and, in step d), only the three most advantageous values from said more than three intensity values are selected and used to compute the reference object phase for each pixel.

4. A method as recited in claim 1, wherein, in step g), steps a) and b) are repeated more than two times with the grid being located at more than two different known positions relative to the camera and to the

object to yield more than three intensity values and, in step d) only the three most advantageous values form said more than three intensity values are selected and used to compute the object phase for each pixel.

5. A method as recited in claim 1, wherein, in step c), said different known positions of the grid are chosen so as to provide in step g) at least two images of the object having a 180 degrees difference in phase therebetween.

6. A method as recited in claim 5, wherein a two-dimensional image of the object is computed by subtracting said at least two images of the object having a 180 degrees difference in phase therebetween; said two dimensional image being used to perform a preliminary analysis of the object.

7. A method as recited in claim 1, wherein, in step g), said different known positions of the grid are chosen so as to provide at least two images of the reference object having a 180 degrees difference in phase therebetween.

8. A method as recited in claim 7, wherein a two-dimensional image of the reference object is computed by subtracting said at least two images of the reference object having a 180 degrees difference in phase therebetween; said two dimensional image being used to perform a preliminary analysis of the reference object.

9. A method as recited in claim 1, wherein said reference object is a plane surface.

10. A method as recited in claim 1, wherein said reference object is said object at a past predetermined time and said reference object phase is computed around said past time; whereby step i) provides the variation of height at each pixel between said past time and the approximate time when the object phase is computed; and step j) yield the variation with time of relief of the object.

11. A method as recited of claim 1, wherein said reference object is a CAD of the object; said grid being virtually positioned and projected into said CAD in step a) and said image of said reference object being simulated in step b).

12. A method for measuring the height of a module including at least one object mounted on a generally plane substrate using a camera provided with an array of pixels, said method comprising:

l) projecting a grid onto the module; the grid being located at a first position relative to the camera and to the module;

m) taking, with the camera, an image of the module illuminated by said projected grid; said image of the module having intensity values for each pixel;

n) repeating steps a) and b) at least two times with the grid being located at two different known positions relative to the camera and to the module to yield at least three intensity values for each pixel;

o) computing the module phase for each pixel using the at least three module intensity values for the corresponding pixel;

p) computing a complementary phase of the substrate by using said at least three intensity values from pixels on the image of the module not corresponding to said at least one object;

q) computing the height of said at least one object for each pixel using said complementary phase of the substrate and said module phase for the corresponding pixel;

r) projecting the grid onto a reference plane; the grid being located at said first position;

s) taking with the camera an image of the reference plane illuminated by said projected grid; said image of the reference plane having intensity values for each pixel position;

t) repeating steps g) and h) at least two times with the grid being located at said two different positions to yield at least three intensity values for each pixel;

u) computing the reference plane phase for each pixel position using the at least three reference plane intensity values for the corresponding pixel;

v) computing the height of the substrate for each pixel using said complementary plane phase of the substrate and said reference plane phase for the corresponding pixel; and

w) computing the height of the module by adding the height of the substrate and the height of said at least one object.

13. The use of the method of claim 12 for lead-coplanarity inspection.

14. A system for measuring the relief of an object, said system comprising:

a grid projecting assembly; said grid projecting assembly including a grid, an illuminating assembly that includes a light source to be projected through said grid onto the object and a projector to project the grid onto the object; said grid being mounted to a support;

an image acquisition apparatus including a camera provided with an array of pixels;

a computer configured for

a) positioning said grid relative to said object and to said image acquisition apparatus;

b) receiving from the image acquisition apparatus at least three images of the projected grid onto the object and at least three images of the projected grid onto a reference object; each of said images of the projected grid onto the object corresponding to a different known position of the grid; each of said images of the projected grid onto the reference object corresponding to one of said known positions of the grid;

c) computing the reference object phase for each pixel using the at least three reference object intensity values for the corresponding pixel;

d) computing the object phase for each pixel using the at least three object intensity values for the corresponding pixel; and

e) computing the difference of height between the object and the reference object for each pixel using said reference object phase and said object phase for the corresponding pixel.

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PATENT COOPERATION TREATY

REC'D 23 OCT 2001
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INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference CF/12657.13	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/CA00/00834	International filing date *(day/month/year)* 14/07/2000	Priority date *(day/month/year)* 14/07/1999
International Patent Classification (IPC) or national classification and IPC G01B11/24		
Applicant SOLVISION INC. et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 9 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 11 sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the report
   II ☐ Priority
   III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   IV ☐ Lack of unity of invention
   V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   VI ☐ Certain documents cited
   VII ☒ Certain defects in the international application
   VIII ☒ Certain observations on the international application

Date of submission of the demand 13/12/2000	Date of completion of this report 19.10.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Baumann, M Telephone No. +49 89 2399 2447

Form PCT/IPEA/409 (cover sheet) (January 1994)

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:

   Description, pages:

1-4,7-26	as originally filed			
5,6,6A-6B	as received on	17/05/2001	with letter of	17/05/2001

   Claims, No.:

1-14	as received on	17/05/2001	with letter of	17/05/2001

   Drawings, sheets:

1/15-15/15	as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:
- ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	3-8,10-14
	No:	Claims	1,2,9
Inventive step (IS)	Yes:	Claims	3,4,11-13
	No:	Claims	1,2,5-10,14
Industrial applicability (IA)	Yes:	Claims	1-14
	No:	Claims	

2. Citations and explanations
   see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

Re Item V (novelty, inventive step, industrial applicability)

Reference is made to the following documents of the search report:

D1: EP-A-0 182 469 (NEW YORK INST TECHN) 28 May 1986 (1986-05-28)

D2: WO 98 55826 A (ELECTRONIC PACKAGING SERVICES ;WANG YINYAN (US)) 10 December 1998 (1998-12-10)

D3: WO 88 02847 A (EASTMAN KODAK CO) 21 April 1988 (1988-04-21)

• Negative statements

1. **Lack of novelty (Article 33(2) PCT)**

1.1. **The independent claim 1** is not new over document D1 which discloses (the reference in parenthesis referring to D1):

A method for measuring the relief of an object (cf. title and abstract; Figure 7) using a camera (detector, 120; claim 1) provided with an array of pixels (image sensing array; page 12, first paragraph), said method comprising (cf. page 5, paragraphs 1 and 2; page 21, last paragraph; Figures 4A, 4B, 5, 8A, and 8B; page 23, second paragraph):
(a) projecting a grid on a reference object (reference plane); the grid being located at a first position relative to the camera and to the reference object; (b) taking, with the camera (linear array camera, 1420), an image of the reference object illuminated by said projected grid; said image of the reference object having intensity values for each pixel; repeating steps (a) and (b) at least two times (three frames each of reference plane; translation of grating, cf. page 25 first paragraph; Figure 8A) with the grid being located at two different known positions relative to the camera and to the reference object to yield at least three intensity values for each pixel; (d) computing the reference object phase for each pixel using the at least three reference object intensity values for the corresponding pixel (Figure 8A); (e) projecting the grid on the object; the grid being located at said first position; (f) taking with the camera an image of the object (implicit) by said projected grid; said image of the object having intensity values for each pixel position (implicit); (g) repeating steps (e) and (f) at least two times with the grid being located at said two different positions to yield at least three intensity values for each pixel (Figure 8A); (h) computing the object phase for each pixel position using the at least three object intensity values for the corresponding pixel (Figure 8A); (i) computing the difference of height between the object and the reference object for each pixel using said reference object phase and said object phase for the corresponding pixel (Figures 4B and 8B; pages 25-26); and (j) using the difference of heights between the object and the reference object to detremine the relief of the object

(eg. Figure 10 shows an object's relief).

1.2. **The dependent claims 2 and 9** are not new over document D1:

Claim 2: in D1, the same system of intensity value equations (cf. D1: page 25) as used in the present application is solved for each pixel of the images. In D2, the same set of equations (cf. D2: abstract, equations on page 6) are also used.

Claim 9: a reference plane is also used in D1 as reference object (cf. D1: page 21, last paragraph; Figure 5).

2. Lack of inventive step (Article 33(3) PCT)

The following claims do not involve an inventive step, because the person skilled in the art would arrive at the subject-matter of those claims by combining the teaching from closest prior art document D1 with teaching of documents D2 or D3:

2.1. **Independent claim 14:**
Document D1 discloses (the references in parenthesis referring to the document D1):

A system for measuring the relief of an object (Figures 1 and 14), the system comprising:
• a grid projecting assembly (grating projector, 1410), including a grid (G; Figure 7), an illuminating assembly including a light source (eg. laser, 111; Figure 2) to be projected through the grid onto the object, a projector to project the grid onto the object;
• an image acquisition apparatus including a camera provided with an array of pixels (linear array camera, 1420);
• a computer (processor, 150; digital computer associated with memory and peripherals; page 12, first paragraph) configured for
- receiving images of the projected grid on a reference object from the image acquisition apparatus;
- computing the reference object phase for each pixel using the at least three reference object intensity values for the corresponding pixel (Figure 4A; page 16, second paragraph;
- computing the object phase for each pixel using the at least three object intensity values for the corresponding pixel (Figure 4A); and
- computing the difference of height between the object and the reference object for each pixel using said reference object phase and said object phase for the corresponding pixel (Figure 4B).

The difference between the subject-matter of claim 14 and D1 is that in claim 14, the grid is mounted on a support and that the computer is configured for positioning the grid relative to the object and the image acquisition system.

The problem to be solved could therefore be regarded as how to change the relative position of the surface to be measured with respect to the grid.

In D1, for instance, the problem is solved in that the object is mounted on a rotary stage (1490; Figure 13A), the movement of the rotary stage being controlled by a processor (1470, Figure 14) which allows to change the position of the object's surface relative to the grid and the acquisition system. If confronted with the problem, the person skilled in the art would, without involving an inventive step, consider either to change the position of the grid or that of the object to be measured. Furthermore, controlling the movements of a system's component, in this case the grid mounted on a support, with a computer lies within the general trend of the technique.

2.2 **Dependent claims 5 and 6 relating to the reference object, and claims 7 and 8 relating to the object:**
In the interferometry method described in D2, the Moiré fringe patterns are computed using the Light Intensity Equations (cf. D2, page 6, lines 12-14) with different phase values, two of which have 180 degrees, ie. π rad, difference. The relative position of the object/reference object is sequentially chosen as to create four phase-shifted Moiré fringe patterns (cf. D2: page 6, lines 3-11). The thus obtained intensity images are then subtracted (cf. D2: equation page 7). The result is then used for further data processing steps, eg. filtering smoothing, as described in D2 to provide preliminary analysis of the object/reference object.

2.3. **Dependent claim 10:**
The embodiment on page 20 of D2 also describes an interferometry method to determine the variation of the object's surface with temperature over time. For that purpose, the measurements are repeated to determine the change in surface flatness, ie. variations of heights, of the object (cf. D2: page 20, lines 6-14).

2.4. Claims 5, 6, 7, 8, 10, and 14 do therefore not involve an inventive step (Article 33(3) PCT).

- **Positive statements**

3.1. The closest prior art document D1 shows a method for measuring the relief of an object as cited under paragraph 1.1. above. In the **independent method claim 11**, which refers to claim 1, such a method is claimed, however with the reference object being replaced by a CAD of the object.

The subject-matter of claim 11 differs from that of D1 in that:
- a CAD of the object is used instead of a reference object;
- the grid is virtually positioned and projected into said CAD; and
- the reference object is simulated.

This method allows an easier control of the positioning of the grid with respect to the reference object, ie. the CAD, thus improving the accuracy of the measurements.

In D3, a CAD of the object is employed only to find a starting location for the image reconstruction process, whereas in the present application, the CAD of the object replaces the reference object. Although most technical features are known from documents D1, D2 and D3, the prior art does not teach nor suggest to combine those features and use them in an interferometry method and for the purposes as claimed.

3.2. The closest prior art document D1 shows a method for measuring the relief of an object as cited under paragraph 1.1. above. The interferometry method defined in the **independent claim 12** is used in particular for measuring the height of a module consisting of at least one object mounted on a substrate.

The subject-matter of claim 12 differs from that of D1 in that:
- a complementary phase of the substrate is measured and subsequently is used to compute the height of the object;
- the height of the substrate for each pixel is computed using the complementary phase of the substrate and the phase of a reference plane for the corresponding pixel; and
- the height of the module is computed by adding the height of the substrate and the height of the object.

The method, which employs an approximation of the surface of the substrate as a complementary reference object, allows to measure the height of a module, especially when the substrate is not parallel to a plane surface, with a high accuracy without increasing the computation time.

The prior art does not teach nor suggest to compute an approximation of the surface of the substrate as a second reference object in order to derive the height of a module in a manner as claimed.

3.3. **The independent claim 13** refers to the use of the method defined in claim 12 for lead-coplanarity inspectoin. Claim 12 being novel and inventive, claim 13 is also novel and inventive in the sense of Article 33(2) and (3) PCT.

3.4. In **claims 3 and 4** depending of claim 1, it is defined that additional images of the reference object and the object, respectively, are taken to allow for the selection of the most advantageous intensity values for *a particular pixel*. In prior art, however, taking additional images has the purpose of increasing the precision of the phase computation by using *all values* in higher order computations.

3.5. Claims 3, 4, and 11-13 are therefore novel and involve an inventive step in the sense of Article 33(2) and (3) PCT.

4. All claims are doubtless industrally applicable (Article 33(4) PCT).

<u>Re Item VII</u> (Certain defects)

1. Independent claims 1, 12, and 14 are not in the two-part form in accordance with Rule 6.3(b) PCT, which in the present case would be appropriate, with those features known in combination from the prior art (document D1) being placed in the preamble (Rule 6.3(b)(i) PCT) and with the remaining features being included in the characterising part (Rule 6.3(b)(ii) PCT).

2. The features of the claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).

3. The documents D1, D2, and D3 have not been identified in the description and the relevant background art briefly discussed. A document reflecting the prior art described on pages 1-4 is not identified in the description (Rule 5.1(a)(ii) PCT).

<u>Re Item VIII</u> (Certain observations)

1. **Lack of clarity of claims (Article 6 PCT):**

1.1. **Claim 1:** In the method steps (c) and (g), it is unclear whether during the repetition of the steps (a) and (b), and (e) and (f), respectively, the grid is being located at <u>at least</u> two different known position relative to the camera and the reference object or not.

1.2. **Claim 5 and claim 6, and 7 and 8:** Ambiguity arises due to the fact that claims 5 and 6 refer to step (c) of claim 1, which deals with the <u>reference object</u>, whereas claims 5 and 6 refer to <u>the object</u>. The same applies to claims 7 and 8 dealing with the reference object, for their reference to the object of step (g) of claim 1.

2. **Contradiction between claims and description (Article 6 PCT):**

2.1. **Claims 6 and 8:** In the description (page 19, line 13) the two dimensional image of the object and the reference object, respectively, is inferred by adding the at least two images having 180 degrees difference in phases therebetween. In claims 6 and 8, however, a substraction (page 28, line 11 and line 22) is claimed.

2.2. The vague and imprecise statement "...spirit of the invention..." in the description on page pages 9 (line 16), 13 (line 21), 22 (line 18), 26 (line 8) implies that the subject-matter for which protection is sought may be different to that defined by the claims, thereby resulting in lack of clarity when used to interpret them.

e) projecting the grid on the object; the grid being located at the first position;

f) taking with the camera an image of the object illuminated by the projected grid; the image of the object having intensity values for each pixel position;

g) repeating steps e) and f) at least two times with the grid being located at the two different positions to yield at least three intensity values for each pixel;

h) computing the object phase for each pixel position using the at least three object intensity values for the corresponding pixel;

i) computing the difference of height between the object and the reference object for each pixel using the reference object phase and the object phase for the corresponding pixel; and

j) using the difference of heights between the object and the reference object for each pixel to determine the relief of the object.

According to a another aspect of the present invention, there is provided a method for measuring the height of a module including at least one object mounted on a generally plane substrate using a camera provided with an array of pixels, the method comprising:

a) projecting a grid onto the module; the grid being located at a first position relative to the camera and to the module;

b) taking, with the camera, an image of the module illuminated by the projected grid; the image of the module having intensity values for each pixel;

c) repeating steps a) and b) at least two times with the grid being located at two different known positions relative to the camera and to the module to yield at least three intensity values for each pixel;

d) computing the module phase for each pixel using the at least three module intensity values for the corresponding pixel;

e) computing a complementary phase of the substrate by using the at least three intensity values from pixels on the image of the module not corresponding to the at least one object;

f) computing the height of the at least one object for each pixel using the complementary phase of the substrate and the module phase for the corresponding pixel;

g) projecting the grid onto a reference plane; the grid being located at the first position;

h) taking with the camera an image of the reference plane illuminated by the projected grid; the image of the reference plane having intensity values for each pixel position;

i) repeating steps g) and h) at least two times with the grid being located at the two different positions to yield at least three intensity values for each pixel;

j) computing the reference plane phase for each pixel position using the at least three reference plane intensity values for the corresponding pixel;

k) computing the height of the substrate for each pixel using the complementary plane phase of the substrate and the reference plane phase for the corresponding pixel; and

computing the height of the module by adding the height of the substrate and the height of the at least one object.

According to another aspect of the present invention, there is also provided a system for measuring the relief of an object, the system comprising:

a grid projecting assembly; the grid projecting assembly including a grid, an illuminating assembly that includes a light source to be projected through the grid onto the object and a projector to project the grid onto the object; the grid being mounted to a support;

an image acquisition apparatus including a camera provided with an array of pixels;

a computer configured for

a) positioning the grid relative to the object and to the image acquisition apparatus;

b) receiving from the image acquisition apparatus at least three images of the projected grid onto the object and at least three images of the projected grid onto a reference object; each of the images of the projected grid onto the object corresponding to a different known position of the grid; each of the images of the projected grid onto the reference object corresponding to one of the known positions of the grid;

c) computing the reference object phase for each pixel using the at least three reference object intensity values for the

corresponding pixel;

d) computing the object phase for each pixel using the at least three object intensity values for the corresponding pixel; and

e) computing the difference of height between the object and the reference object for each pixel using the reference object phase and the object phase for the corresponding pixel.

Other objects, advantages and features of the present invention will become more apparent upon reading the following non-restrictive description of preferred embodiments thereof, given by way of example only, with reference to the accompanying drawing

BRIEF DESCRIPTION OF THE DRAWINGS

In the appended drawings:

Figure 1 is a schematic view of a system for inspecting the surface of an object according to an embodiment of the present invention;

Figure 2 is a schematic view of both the image acquisition apparatus and the grid projection assembly of Figure 1;

WHAT IS CLAIMED IS:

1. A method for measuring the relief of an object using a camera provided with an array of pixels, said method comprising:

a) projecting a grid on a reference object; the grid being located at a first position relative to the camera and to the reference object;

b) taking, with the camera, an image of the reference object illuminated by said projected grid; said image of the reference object having intensity values for each pixel;

c) repeating steps a) and b) at least two times with the grid being located at two different known positions relative to the camera and to the reference object to yield at least three intensity values for each pixel;

d) computing the reference object phase for each pixel using the at least three reference object intensity values for the corresponding pixel;

e) projecting the grid on the object; the grid being located at said first position;

f) taking with the camera an image of the object illuminated by said projected grid; said image of the object having intensity values for each pixel position;

g) repeating steps e) and f) at least two times with the grid being located at said two different positions to yield at least three intensity values for each pixel;

h) computing the object phase for each pixel position using the at least three object intensity values for the corresponding pixel;

i) computing the difference of height between the object and the reference object for each pixel using said reference object phase and said object phase for the corresponding pixel; and

j) using said difference of heights between the object and the reference object for each said pixel to determine the relief of the object

2. A method as recited in claim 1, wherein, in at least one of steps d) and h), the phase $\Delta\Phi$ is computed for each pixel by solving the following system of equations:

$$I_n = A + B \cdot \cos(\Delta\Phi + \Delta\varphi_n)$$

where I_n represent the at least three intensity values, A and B are known coefficients and $\Delta\varphi_n$ are phase variations caused by the different locations of the grid.

3. A method as recited in claim 1, wherein, in step c), steps a) and b) are repeated more than two times with the grid being located at more than two different known positions relative to the camera and to the reference object to yield more than three intensity values and, in step d), only the three most advantageous values from said more than three intensity values are selected and used to compute the reference object phase for each pixel.

4. A method as recited in claim 1, wherein, in step g), steps a) and b) are repeated more than two times with the grid being located at more than two different known positions relative to the camera and to the

object to yield more than three intensity values and, in step d) only the three most advantageous values form said more than three intensity values are selected and used to compute the object phase for each pixel.

5. A method as recited in claim 1, wherein, in step c), said different known positions of the grid are chosen so as to provide in step g) at least two images of the object having a 180 degrees difference in phase therebetween.

6. A method as recited in claim 5, wherein a two-dimensional image of the object is computed by subtracting said at least two images of the object having a 180 degrees difference in phase therebetween; said two dimensional image being used to perform a preliminary analysis of the object.

7. A method as recited in claim 1, wherein, in step g), said different known positions of the grid are chosen so as to provide at least two images of the reference object having a 180 degrees difference in phase therebetween.

8. A method as recited in claim 7, wherein a two-dimensional image of the reference object is computed by subtracting said at least two images of the reference object having a 180 degrees difference in phase therebetween; said two dimensional image being used to perform a preliminary analysis of the reference object.

9. A method as recited in claim 1, wherein said reference object is a plane surface.

10. A method as recited in claim 1, wherein said reference object is said object at a past predetermined time and said reference object phase is computed around said past time;
whereby step i) provides the variation of height at each pixel between said past time and the approximate time when the object phase is computed; and step j) yield the variation with time of relief of the object.

11. A method as recited of claim 1, wherein said reference object is a CAD of the object; said grid being virtually positioned and projected into said CAD in step a) and said image of said reference object being simulated in step b).

12. A method for measuring the height of a module including at least one object mounted on a generally plane substrate using a camera provided with an array of pixels, said method comprising:

l) projecting a grid onto the module; the grid being located at a first position relative to the camera and to the module,

m) taking, with the camera, an image of the module illuminated by said projected grid; said image of the module having intensity values for each pixel;

n) repeating steps a) and b) at least two times with the grid being located at two different known positions relative to the camera and to the module to yield at least three intensity values for each pixel;

o) computing the module phase for each pixel using the at least three module intensity values for the corresponding pixel;

p) computing a complementary phase of the substrate by using said at least three intensity values from pixels on the image of the module not corresponding to said at least one object;

q) computing the height of said at least one object for each pixel using said complementary phase of the substrate and said module phase for the corresponding pixel;

r) projecting the grid onto a reference plane; the grid being located at said first position;

s) taking with the camera an image of the reference plane illuminated by said projected grid; said image of the reference plane having intensity values for each pixel position;

t) repeating steps g) and h) at least two times with the grid being located at said two different positions to yield at least three intensity values for each pixel;

u) computing the reference plane phase for each pixel position using the at least three reference plane intensity values for the corresponding pixel;

v) computing the height of the substrate for each pixel using said complementary plane phase of the substrate and said reference plane phase for the corresponding pixel; and

w) computing the height of the module by adding the height of the substrate and the height of said at least one object.

13. The use of the method of claim 12 for lead-coplanarity inspection.

14. A system for measuring the relief of an object, said system comprising:

a grid projecting assembly; said grid projecting assembly including a grid, an illuminating assembly that includes a light source to be projected through said grid onto the object and a projector to project the grid onto the object; said grid being mounted to a support;

an image acquisition apparatus including a camera provided with an array of pixels;

a computer configured for

a) positioning said grid relative to said object and to said image acquisition apparatus;

b) receiving from the image acquisition apparatus at least three images of the projected grid onto the object and at least three images of the projected grid onto a reference object; each of said images of the projected grid onto the object corresponding to a different known position of the grid; each of said images of the projected grid onto the reference object corresponding to one of said known positions of the grid;

c) computing the reference object phase for each pixel using the at least three reference object intensity values for the corresponding pixel;

d) computing the object phase for each pixel using the at least three object intensity values for the corresponding pixel; and

e) computing the difference of height between the object and the reference object for each pixel using said reference object phase and said object phase for the corresponding pixel.

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference CF/12657.13	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/CA 00/ 00834	International filing date *(day/month/year)* 14/07/2000	(Earliest) Priority Date *(day/month/year)* 14/07/1999
Applicant 9071 9410 QUEBEC INC.(SOLVISION)		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

a. With regard to the **language,** the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

[ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

[ ] contained in the international application in written form.

[ ] filed together with the international application in computer readable form.

[ ] furnished subsequently to this Authority in written form.

[ ] furnished subsequently to this Authority in computer readble form.

[ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

[ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

[X] the text is approved as submitted by the applicant.

[ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract,**

[X] the text is approved as submitted by the applicant.

[ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 2,4

[X] as suggested by the applicant.

[ ] because the applicant failed to suggest a figure.

[ ] because this figure better characterizes the invention.

[ ] None of the figures.

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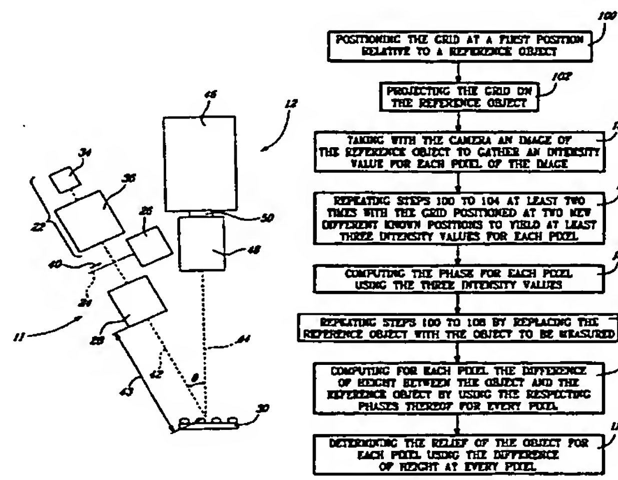
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHOD AND SYSTEM FOR MEASURING THE RELIEF OF AN OBJECT



(57) Abstract: A method and a system for measuring the relief of an object are described herein. The system includes a grid projecting for projecting a grid, an image acquisition apparatus that includes a camera, and a computer. Providing a reference object having common elements with the object to measure, the method includes the steps of a) positioning the grid at three different known positions relative to the camera and the common elements; b) for each position of the grid, projecting the grid unto the reference object and, with the camera, taking an image of the reference object to yield three images having values for each pixel of the camera and c) computing the reference object phase for each pixel using the three reference object intensity values for the corresponding pixel. Steps a), b) and c) are repeated by replacing the reference object by the object to be measured. The difference of height between the object to be measured and the reference object for each pixel are then computed by subtracting the reference object phase and the object phase for the corresponding pixel.

WO 01/06210 A1

TITLE OF THE INVENTION

METHOD AND SYSTEM FOR MEASURING THE RELIEF OF AN OBJECT

FIELD OF THE INVENTION

The present invention generally relates to methods for measuring the relief of an object. More specifically, the present invention is concerned with the use of such systems and methods to inspect the lead coplanarity on circuit board.

BACKGROUND OF THE INVENTION

The use of interferometric methods to inspect the surface of an object for defects or to measure the relief of an object is well known. Generally stated, these methods consist in generating an interferometric pattern on the surface of the object and then analyzing the resulting interferometric image (or interferogram) to obtain the relief of the object. The interferometric image generally includes a series of black and white fringes.

Interferometric methods that require the use of a laser to generate the interferometric pattern are called "classic interferometric methods". In such classic methods, the wavelength of the laser and the configuration of the measuring assembly generally determine the period of the resulting interferogram. Classic interferometry methods are

generally used in the visible spectrum to measure height variations in the order of micron.

However, it has been found difficult to use such method to measure height variations (relief) on a surface showing variations beyond 0.5 – 1 µm when they are implemented in the visible spectrum. Indeed, the density of the black and white fringes of the resulting interferogram increases, causing its analysis to be tedious.

Another drawback of classic interferometric methods is that they require measuring assemblies that are particularly sensitive to noise and vibrations.

Surface inspection methods based on Moiré interferometry allow measuring the relief of an object in the visible spectrum with accuracy much more than the accuracy of classic interferometric methods. These methods are based on the analysis of the frequency beats obtained between 1) a grid positioned over the object to be measured and its shadow on the object ("Shadow Moiré Techniques") or 2) the projection of a grid on the object and another grid positioned between the object and the camera that is used to take a picture of the resulting interferogram ("Projected Moiré Techniques"). In both cases, the frequency beats between two grids produce the fringes of the resulting interferogram.

More specifically, the Shadow Moiré technique includes the steps of positioning a grid near the object to be measured, providing

illumination from a first angle from the plane of the object (for example 45 degrees) and using a camera, positioned at a second angle (for example 90 degrees from the plane of the object), to take pictures of the interferogram.

Since the distance between the grid and the object varies, this variation of height produces a variation in the pattern of the interferogram. This variation in the pattern can then be analysed to obtain the relief of the object.

A drawback to the use of a Shadow Moiré technique for measuring the relief of an object is that the grid must be positioned very close to the object in order to yield accurate results, causing restrictions in the set-up of the measuring assembly.

The Projected Moiré technique is very similar to the Shadow Moiré technique since the grid, positioned between the camera and the object, has a function similar to the shadow of the grid in the Shadow Moiré technique. However, a drawback of the Projected Moiré technique is that it involves many adjustments and therefore creates more risk of inaccuracy in the results since it requires the positioning and tracking of two grids. Furthermore, the second grid tend to obscure the camera, preventing it from being used simultaneously to take other measurements.

A method and a system to measure the relief of an object free of the above-mentioned drawbacks of the prior-art are thus desirable.

OBJECTS OF THE INVENTION

An object of the present invention is therefore to provide an improved method and system for measuring the relief of an object.

Another object of the invention is to provide such a system suitable for lead coplanarity inspection.

SUMMARY OF THE INVENTION

More specifically, in accordance with the present invention, there is provided a method for measuring the relief of an object using a camera provided with an array of pixels, the method comprising:

a) projecting a grid on a reference object; the grid being located at a first position relative to the camera and to the reference object;

b) taking, with the camera, an image of the reference object illuminated by the projected grid; the image of the reference object having intensity values for each pixel;

c) repeating steps a) and b) at least two times with the grid being located at two different known positions relative to the camera and to the reference object to yield at least three intensity values for each pixel;

d) computing the reference object phase for each pixel using the at least three reference object intensity values for the corresponding pixel;

e) projecting the grid on the object; the grid being located at the first position;

f) taking with the camera an image of the object illuminated by the projected grid; the image of the object having intensity values for each pixel position;

g) repeating steps e) and f) at least two times with the grid being located at the two different positions to yield at least three intensity values for each pixel;

h) computing the object phase for each pixel position using the at least three object intensity values for the corresponding pixel; and

i) computing the difference of height between the object and the reference object for each pixel using the reference object phase and the object phase for the corresponding pixel.

According to another aspect of the present invention, there is provided a system for measuring the relief of an object, the system comprising:

a grid projecting assembly;

an image acquisition apparatus including a camera provided with an array of pixels;

a computer configured for

a) receiving from the image acquisition apparatus at least three images of the projected grid onto the object and at least three images of the projected grid onto the reference object; each of the images

of the projected grid onto the object corresponding to a different known position of the grid; each of the images of the projected grid onto the reference object corresponding to one of the known positions of the grid;

b) computing the reference object phase for each pixel using the at least three reference object intensity values for the corresponding pixel;

c) computing the object phase for each pixel using the at least three object intensity values for the corresponding pixel; and

d) computing the difference of height between the object and the reference object for each pixel using the reference object phase and the object phase for the corresponding pixel.

Other objects, advantages and features of the present invention will become more apparent upon reading the following non-restrictive description of preferred embodiments thereof, given by way of example only, with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the appended drawings:

Figure 1 is a schematic view of a system for inspecting the surface of an object according to an embodiment of the present invention;

Figure 2 is a schematic view of both the image acquisition apparatus and the grid projection assembly of Figure 1;

Figure 3 is a schematic view illustrating the projection of a grid on an object;

Figure 4 is a block diagram of a method for measuring the relief of an object according to an embodiment of the present invention;

Figure 5 is an image of a sphere mounted to a board, as taken by the system of Figure 1;

Figure 6 is an image of the board of Figure 5, illuminated by the grid;

Figure 7 is an image computed by the system of Figure 1, representing the phase of the board of Figure 6;

Figure 8 is an image of the sphere of Figure 5 mounted to the board, illuminated by the grid;

Figure 9 is an image computed by the system of Figure 1, representing the phase of the sphere with the board of Figure 8;

Figure 10 is an image illustrating the phase variation between the images of Figures 7 and 9;

Figure 11 is an image representing the phase variation

between a module comprising lead balls on a substrate and a reference surface;

Figure 12 is an image representing the phase of the module of Figure 11;

Figure 13 is an image representing the phase variation between the phase of the image of Figure 12 and the phase image of a complementary surface;

Figure 14 is an image representing the phase variation between the phases of the images of the complementary surface and the reference plane;

Figure 15 is the image of Figure 14 after unwrapping.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Turning now to Figures 1 and 2 of the appended drawings, a system 10 for measuring the relief of an object, according to an embodiment of the present invention, will be described.

The surface inspection system 10 comprises a grid projecting assembly 11, an image acquisition apparatus 12, and a computer 14 advantageously provided with a storing device 16, an output device 18 and an input device 20.

Turning now more specifically to Figure 2 of the appended drawings, the grid projecting assembly 11 and the image acquisition apparatus 12 will be described in more detail.

The grid projection assembly 11 includes an illuminating assembly 22, a grid 24 mounted to a movable support 26 and a projector 28.

The illuminating assembly 22 advantageously includes a source of white light 34 that is projected through the grid 24. For example, the source 34 is the end of an optical fiber (not shown) providing light from a white light source (not shown). An aspherical lens 36 or any other condenser is also advantageously used between the source 34 and the grid 24. Other light sources may also be used. It is also believed to be within the reach of a person skilled in the art to conceive another illuminating assembly within the spirit of the present invention.

The configuration of the grid 24 may vary depending on the resolution that is required to adequately measure the relief of the object 30. For example, it has been found that a ronchi ruling having 250 lines per inch allows to measure lead coplanarity of a circuit board, where a resolution around 1 mm is required.

The grid 24 is advantageously mounted to a moveable support 26 that allows displacement of the grid 24 in a direction perpendicular (see double arrow 40 on Figure 2) to both the lines on the grid 24 and to the direction of incidence of the light (dashed line 42 on

Figure 2).

The movable support 26 is actuated by a stepping motor (not shown). The stepping motor is advantageously controlled by a micro-controller (not shown) triggered by the computer 14. Of course, the stepping motor could be directly controlled by the computer 14.

A projector 28, in the form of a 50 mm TV lens, is advantageously used to project the grid 24 onto the object 38.

The angle θ between the direction of incidence of the light (dashed line 42 on Figure 2) and the line of sight of the image acquisition apparatus 12 (dashed line 44 on Figure 2) may vary depending on the nature of the object 30 to be measured.

It is believed to be within the reach of a person skilled in the art to position the illuminating assembly 22, the grid 24 and the grid projector 28 relative to the object 30 to yield a projected grid having the desired pitch *p* onto the object 30.

For example, a ronchi grid, having a density of 250 lines per inch, with a distance 43 of 22 cm between the object 30 and the projector 28, and for an angle θ of 30 degrees, provides a projected grid having a 0.5 mm pitch *p*. Such a pitch is equivalent to a variation of height of about 1 mm on the surface of the object 30.

Obviously, the pitch of the projected grid will vary with the

pitch of the grid 24.

As will be explained hereinbelow, the displacement of the projected grid 24 on the object 30 may alternatively be achieved by fixing the position of the grid 24 and by moving the object 30 and the camera 46 together.

It is to be noted that the system 10 does not require a grid between the camera 46 and the object 30. This advantage will be discussed hereinbelow.

The image acquisition apparatus 12 includes a camera 46, provided with an array of pixels, and is advantageously in the form of a CCD camera 46. Such a camera provides, for example, a resolution of 1300x1024 pixels.

The image acquisition apparatus 12 also advantageously includes a telecentric lens 48, advantageously mounted to the camera 46 via an optional extension tube 50.

The configuration of the image acquisition apparatus 12 and the distance between the apparatus 12 and the object 30 determines the field of view of the image acquisition apparatus 12. Alternatively, a desired field of view can be achieved without the extension tube 50 by distancing the camera 46 from the object 30.

The CCD camera can be replaced by a conventional

camera when the computer 14 is configured to digitize the acquired images.

The computer 14 is advantageously configured to control the displacement of the grid 24, to process the images of the object 30 taken by the camera 46 and to analyze these images to measure the relief of the object 30.

The computer 14 is advantageously provided with memory means allowing storing of the images when they are processed by the computer 14 and therefore increasing the processing speed.

The storing device 16 can be, for example, a hard drive, a writable CD-ROM drive or other well-known data storing means. It can be directly connected to the computer 14, or remotely connected via a computer network such as the Internet. According to an embodiment of the invention, the storing device 16 is used to store both the images taken by the image acquisition apparatus 12, the relief of the object 30 and other intermediary results. Those files can be stored in any format and resolution that can be read by the computer 14.

The output device 20 allows visualization of the images and of the data produced by the computer 14, and can take many forms from a display monitor to a printing device.

The input device 18 can be a conventional mouse, a keyboard or any other well-known input device or combination thereof

which allows inputting of data and commands into the computer 14.

The storing device 16, the display monitor 18 and the input device 20 are all connected to the computer 12 via standard connection means, such as data cables.

The computer 14 can be a conventional personal computer or any other data processing machine that includes a processor, a memory and input/output ports (not shown). The input/output ports may include network connectivity to transfer the images to and from the storing device 16.

Of course, the computer 12 runs software that embodies the method of the present invention thereof, as will be described hereinbelow.

It is to be noted that the system 10 includes adjustable support means (not shown) to position the image acquisition apparatus 12 and the grid projecting assembly 11 relative to each other and to the object 30. Alternatively, other registration means can be used without departing from the nature and spirit of the present invention.

Before giving a detail description of a method for measuring the relief of an object according to an embodiment of the present invention, the general theory underlying such a method will first be described. Since this theory is believed to be well known in the art and for concision purposes, it will only be briefly described herein.

The intensity $I(x,y)$ for every pixel (x,y) on an interferometric image may be described by the following equation:

$$I(x,y) = A(x,y) + B(x,y) \cdot \cos(\Delta\Phi(x,y)) \quad (1)$$

where $\Delta\Phi$ is the phase variation (or phase modulation), and A and B are coefficient that can be computed for every pixel.

Knowing the phase variation $\Delta\Phi$, the object height distribution (the relief) at every point $h(x,y)$ relative to a reference surface can be computed using the following equation (see Figure 3):

$$h(x,y) = \frac{\Delta\Phi(x,y) \cdot p}{2\pi \cdot \tan(\theta)} \quad (2)$$

where p is the grid pitch and θ is the projection angle, as described hereinabove.

Although the above equation is valid for a parallel projection of the grid on the object, as illustrated in Figure 3 (note that the incidence ray 60 from the grid projection are parallel), it is believed to be within the reach of a person skilled in the art to use another equation if the grid projection is not parallel.

For example, it has been found with a pinhole projection that the pitch p and the angle θ increase with the distance from the grid on

the plan of the reference surface (see x on Figure 3). It has been found that with a first order approximation, variations in p and θ cancel each other out and the Equation 2 remains valid within a certain limit of the parameters.

It is believed within the reach of someone skilled in the art to re-evaluate the relation between the variation of height $h(x,y)$ and the phase $\Delta\Phi$, and to make corrections to the relation according to the configuration of the system used to measure the relief.

Turning now to Figure 4 of the appended drawings, a method for measuring the relief of an object according to an embodiment of the present invention will be described in more detail.

Generally stated, the method consists in measuring the relief of an object 30 using the system 10 by performing the following steps:

100 - positioning the grid 24 at a first position relative to a reference object;

102 - projecting the grid 24 on the reference object;

104 - taking, with the camera 46, an image of the reference object to gather an intensity value for each pixel of the image;

106 - repeating steps 100 to 104 at least two times with the grid positioned at two new different known positions to yield at least three intensity values for each pixel;

108 - computing the phase for each pixel using the

three intensity values;

110 - repeating steps 100 to 108 by replacing the reference object with the object 30 to be measured;

112 - computing, for each pixel, the difference of height between the object 30 and the reference object by using the respecting phases thereof for every pixel; and

114 - determining the relief of the object for each pixel using the difference of height at every pixel.

These general steps will now be further described with reference to a first example where the object 62 to measure is a sphere 64 mounted to a board 66. An image of said object 62 can be seen in Figure 5.

By choosing a similar board as the reference object, the difference of height between the object 62 and the reference object will provide the height of the sphere 64. The common element to the object 62 and the reference object is, in this example, the board 66.

In step 100, the grid 24 is moved to a first predetermined position using the support 26 that is actuated by the stepping motor. As it has been discussed hereinabove, the system 10 includes means to register and fix the position of the grid 24 and the camera 46 relative to the reference object (and later the object).

In step 102, the grid 24 is then projected onto the reference object.

In step 104, the camera 46 takes an image of the reference object.

The image includes an intensity value for each pixel of the image. The computer 14 stores these intensity values for future processing.

Steps 100 to 104 are then repeated at least twice with the grid positioned at two new known different positions (step 106). This will provide three slightly different images and therefore the three intensity values for each pixel. One of the three images of the board illuminated by the grid 24 can be seen in Figure 6.

Since Equation 1 comprises three unknowns, that is A, B and $\Delta\Phi$, three intensity values I_1, I_2 and I_3 for each pixel, and therefore three images, are required to compute the phase variation $\Delta\Phi$.

The two new images are taken following small translations of the grid 24 relative to the surface of the reference object. The displacements are so chosen as to yield phase variations in the images $\Delta\varphi_1$, $\Delta\varphi_2$ and $\Delta\varphi_3$. This results in three equations similar to Equation 1 for each pixel of the pixel array of the camera 46:

$$I_n = A + B \cdot \cos(\Delta\Phi + \Delta\varphi_n) \qquad (3)$$

with n=1,3.

By solving the system of Equation 3, one obtains the value of $\Delta\Phi$. The displacements of the grid 24 are chosen so as to advantageously provide different values of $\Delta\varphi_1$, $\Delta\varphi_2$ and $\Delta\varphi_3$.

According to a preferred embodiment of the present invention, more than three images are taken. This yield additional intensity values that can be used to increase the precision of the calculated phase.

Methods according to the prior-art often require the use of four images and all four values from these images are taken for phase estimation. Since a method according to the present invention requires only three images, additional images may be used to increase the precision and reliability of the method.

By keeping, for example, four (or more) images, it is possible to discard noisy pixels or images and to keep only the pixels having the most advantageous intensity values. Indeed, if one of the four intensity values is noisy (that can be caused, for example, by an image saturation), the corresponding intensity can be eliminated without compromising the precision of the resulting phase for this particular pixel.

Alternatively, more then three intensity values can be used to traditionally compute the phase using a numerical method such as a least square fit. However, such a method could not prevent erroneous phase values to be computed for certain pixels, potentially

causing imprecision in the computation of the relief of the object.

According to another preferred embodiment of the present invention, the displacements of the grid between the second and third images (and the fourth image) are chosen so as to provide two images having 180 degrees phase variations $\Delta\varphi_n$ (see Equation 3). This allows obtaining an image of the reference object (or of the object) without the projected grid. This can be achieved by adding the intensity values of the two images phase shifted by 180 degrees.

More generally, if the sum of the phase variations of some of the three or more images taken by the camera 46 is 360 degrees, a corresponding two-dimensional image can be obtained by adding the intensity values of these images for each pixel. This recomposed two-dimensional image does not include the projected grid. This image may be used to perform a preliminary analysis of the reference object (or of the object) that may speed-up any subsequent analysis that will be performed on the image or the values that will result from step 112.

In step 108, the phase is computed using the three intensity values (or the three best intensity values) for each pixel by solving the Equations 3. This can be achieved by using a conventional numerical method, for example. Numerical methods for solving such system of equation are believed to be well known in the art and will not be described herein.

The resulting phase of the reference object for every

pixel is illustrated in Figure 7.

When the method of Figure 4 is used to inspect a series of objects, steps 100 to 108 may be advantageously performed only once for the reference object before the inspection. This allows the increase of the speed of the inspection.

Steps 100 to 108 are repeated by replacing the reference object by the object to measure, i.e. the object 62.

One of the images of the sphere 64 with the board 66, illuminated by the grid 24, can be seen in Figure 8.

Since there is no difference in performing steps 100 to 108 with the object and with the reference object, and for concision purposes, these steps will not be described again by referring to the object.

The resulting phase of the sphere 64, with the board 66, is illustrated in Figure 9. It is to be noted that the zone 68 in the image of Figure 9 is caused by the shadow of the sphere 64.

In step 112, the difference of height between the object 30 and the reference object is computed for every pixel, as obtained in step 108, by subtracting the phase of the reference object from the phase of the inspected object. The resulting image is shown in Figure 10.

It is to be noted that the phases computed in step 108 for the object and for the reference object, and illustrated in Figures 7 and 9, correspond to surface phases relative to an imaginary projection plan.

When a non-parallel projection of the grid 24 is done, this imaginary projection plan becomes slightly curved. This is not detrimental with the method for measuring the relief of an object according to the present invention since both the images of the object and of the reference object are taken with the same system 10.

Since the phases of the object and of the reference object at each pixel correspond to the difference of height between the object (or the reference object) and the same imaginary projection plane (since the same system with the same optical set-up is used), their subtraction yields the difference of height between the object and the reference object. This allows the image acquisition of the object and of the reference object to be performed under different illumination.

In the optional step 114, the relief of the object, i.e. its height, is determined for each pixel using the difference of height at every pixel between the object and the reference object and knowing the dimensions of the reference object.

As will now appear obvious to a person of ordinary skills in the art, a method according to an embodiment of the present invention can be used to measure the difference of height between two objects (one being the reference). In this case, step 114 is obviously not performed.

In some applications, it may be advantageous to use a plane surface on which the object to measure will be laid on during measurement as the reference object.

In some applications, it may be advantageous to provide the system 10 with a registration system to help position the object and the reference object to a known position relative to the camera. Indeed, since a comparison between the object and the reference object is performed for each pixel, a registration system may ensure that corresponding points are compared.

Such registration system may take many forms including indicia on plane surface, a stand or a software program implemented in the computer.

It is to be noted that the images may be first acquired and then processed at a future time without departing from the spirit of the present invention.

As will be apparent upon reading the present description, a method, according to an embodiment of the present invention, allows the measure of the relief of an object using white light.

Although the present invention has been described with an example where spherical objects are measured, it allows the inspection and measurement of objects having other configurations.

The same object may also act as the reference object when the system 10 is used to study the variation in time of an object's relief.

Alternatively, the reference object may be replaced by a computer model of the object, generated, for example, by a Computer Assisted Design (CAD) that would have been virtually positioned according to the set-up of the system 10.

The reference object may also be a similar object having defects within acceptable parameters. Hence, the subtraction of the phases of the object and of the reference object will set forth the defect of the object under inspection. This aspect of the invention is particularly interesting to inspect the relief of an object having important variations of relief.

Indeed, since the phase values are limited in the range 0 to 2π the maximum height h_0 that can be detected by most systems of the prior-art is

$$h_0 = \frac{p}{\tan(\theta)}$$ (see Equation 2).

Usually the unwrapping of phase is done by using a grid having a pitch p sufficiently large to ensure that all height variations will be in a single-phase order (0 to 2π).

A drawback to this is the loss of precision that it implies. For example, if the object to be measured is tilted according to the image acquisition apparatus, the lost of precision may be important.

The following example will illustrate how a method according to the present invention allows prevention of the above drawback and relates to lead coplanarity inspection on a circuit board.

Figure 11 is an image showing the relief of a module 69 comprising a plurality of lead balls 70 on a substrate 72. The image of Figure 11 is obtained by performing steps 110 to 114 of Figure 4. In this example, the object is the module 69 (including the substrate 72 and the lead balls 70) and the reference object is a reference plane surface (not shown).

It can be seen in Figure 11, by the variation in the grey shade in the image, that the substrate 72 is not parallel to a plane surface. Therefore, such image provides less precision in measuring the height of the object than if the substrate would have been plane. Indeed, it is to be noted that the tilt in the substrate 72 on the image is not caused by the system 12, but reflects the actual configuration of the substrate 72. The small variation in height of each lead ball 70 may be lost in the overall variation in the substrate 72 profile.

Although one can conceive a computer algorithm to virtually rectify the substrate on the image, such algorithm may add to the inspection process time. This can be seen as a drawback when the

inspection is performed in real-time on a production line.

The proposed solution is to use an approximation of the surface of the substrate as a second reference object.

Indeed, it may be advantageous, at each pixel, to first find the height of the substrate 72 relative to a plane surface, secondly the height of the lead balls 70 relative to the substrate 72 and to finally add these two heights to provide the overall height of the object, i.e. the substrate with the balls.

The phase of the module is illustrated in Figure 12 and is obtained through steps 100 to 108 of the method of Figure 4.

Information about the surface of the substrate 72 is then obtained by analyzing the pixel corresponding to the substrate 72 (between the balls 70) on the image of Figure 12 where a pseudo-phase image of a complementary surface is computed.

The height of the balls 70 is computed for each pixel (step 112) by subtracting the phase of the module (Figure 12), and the phase of the complementary surface. The resulting image can be seen in Figure 13.

Similarly, the height of the substrate 72 is computed for each pixel (step 112) by subtracting the phase of the complementary surface and the phase of the reference plane. The resulting image can be

seen in Figure 14. This phase image is then unwrapped (see Figure 15).

The height of the module 69 is then obtained by adding the height of the phases of Figures 13 and 15.

Although the present invention has been described hereinabove by way of preferred embodiments thereof, it can be modified without departing from the spirit and nature of the subject invention, as defined in the appended claims.

WHAT IS CLAIMED IS:

1. A method for measuring the relief of an object using a camera provided with an array of pixels, said method comprising:

j) projecting a grid on a reference object; the grid being located at a first position relative to the camera and to the reference object;

k) taking, with the camera, an image of the reference object illuminated by said projected grid; said image of the reference object having intensity values for each pixel;

l) repeating steps a) and b) at least two times with the grid being located at two different known positions relative to the camera and to the reference object to yield at least three intensity values for each pixel;

m) computing the reference object phase for each pixel using the at least three reference object intensity values for the corresponding pixel;

n) projecting the grid on the object; the grid being located at said first position;

o) taking with the camera an image of the object illuminated by said projected grid; said image of the object having intensity values for each pixel position;

p) repeating steps e) and f) at least two times with the grid being located at said two different positions to yield at least three intensity values for each pixel;

q) computing the object phase for each pixel position using the at least three object intensity values for the corresponding pixel; and

r) computing the difference of height between the object and the reference object for each pixel using said reference object phase and said object phase for the corresponding pixel.

2. A method as recited in claim 1, further comprising using said difference of heights between the object and the reference object for each said pixel to determine the relief of the object.

3. A method as recited in claim 1, wherein, in at least one of steps d) and h), the phase $\Delta\Phi$ is computed for each pixel by solving the following system of equations:

$$I_n = A + B \cdot \cos(\Delta\Phi + \Delta\varphi_n)$$

where I_n represent the at least three intensity values, A and B are known coefficients and $\Delta\varphi_n$ are phase variations caused by the different locations of the grid.

4. A method as recited in claim 3, wherein said system of equations is solved using a numerical method.

5. A method as recited in claim 1, wherein, in step c), steps a) and b) are repeated more than two times with the grid being located at more than two different known positions relative to the camera and to the reference object to yield said at least three intensity values and at least one additional value for each pixel and, in step d), a selection is performed among the at least three intensity values and the at least one additional

values to yield the three most advantageous intensity values; said three most advantageous intensity values being used to compute the reference object phase for each pixel.

6. A method as recited in claim 1, wherein, in step c), steps a) and b) are repeated more than two times with the grid being located at more than two different known positions relative to the camera and to the reference object to yield more than three intensity values and, in step d), the three most advantageous values from said more than three most advantageous intensity values are used to compute the reference object phase for each pixel.

7. A method as recited in claim 1, wherein, in step g), steps e) and f) are repeated more than two times with the grid being located at more than two different known positions relative to the camera and to the object to yield said at least three intensity values and at least one additional value for each pixel and, in step h), a selection is performed among the at least three intensity values and the at least one additional values to yield the three most advantageous intensity values and said three most advantageous intensity values are used to compute the object phase for each pixel.

8. A method as recited in claim 1, wherein, in step g), steps a) and b) are repeated more than two times with the grid being located at more than two different known positions relative to the camera and to the object to yield more than three intensity values and, in step d) the three

most advantageous values form said more than three intensity values are used to compute the object phase for each pixel.

9. A method as recited in claim 1, wherein, in step c), said two known positions of the grid are chosen so as to provide at least two images of the object having a 180 degrees difference in phase therebetween.

10. A method as recited in claim 9, wherein a two-dimensional image of the object is computed by subtracting said at least two images of the object having a 180 degrees difference in phase therebetween; said two dimensional image being used to perform a preliminary analysis of the object.

11. A method as recited in claim 1, wherein, in step g), said two known positions of the grid are chosen so as to provide at least two images of the reference object having a 180 degrees difference in phase therebetween.

12. A method as recited in claim 11, wherein a two-dimensional image of the reference object is computed by subtracting said at least two images of the reference object having a 180 degrees difference in phase therebetween; said two dimensional image being used to perform a preliminary analysis of the reference object.

13. A method as recited in claim 1, wherein said reference object is a plane surface.

14. A method as recited in claim 1, wherein said reference object is said object at a past predetermined time and said reference object phase is computed around said past time; whereby step i) provides the variation of height at each pixel between said past time and the approximate time when the object phase is computed.

15. A method as recited of claim 1, wherein said reference object is a CAD of the object; said grid being virtually positioned and projected into said CAD in step a) and said image of said reference object being simulated in step b).

16. A system for measuring the relief of an object, said system comprising:

a grid projecting assembly;

an image acquisition apparatus including a camera provided with an array of pixels;

a computer configured for

a) receiving from the image acquisition apparatus at least three images of the projected grid onto the object and at least three images of the projected grid onto the reference object; each of said images of the projected grid onto the object corresponding to a different known position of the grid; each of said images of the projected grid onto the reference object corresponding to one of said known positions of the grid;

b) computing the reference object phase for each pixel using the at least three reference object intensity values for the corresponding pixel;

c) computing the object phase for each pixel using the at least three object intensity values for the corresponding pixel; and

d) computing the difference of height between the object and the reference object for each pixel using said reference object phase and said object phase for the corresponding pixel.

17. The use of the method of claim 1 for lead-coplanarity inspection.

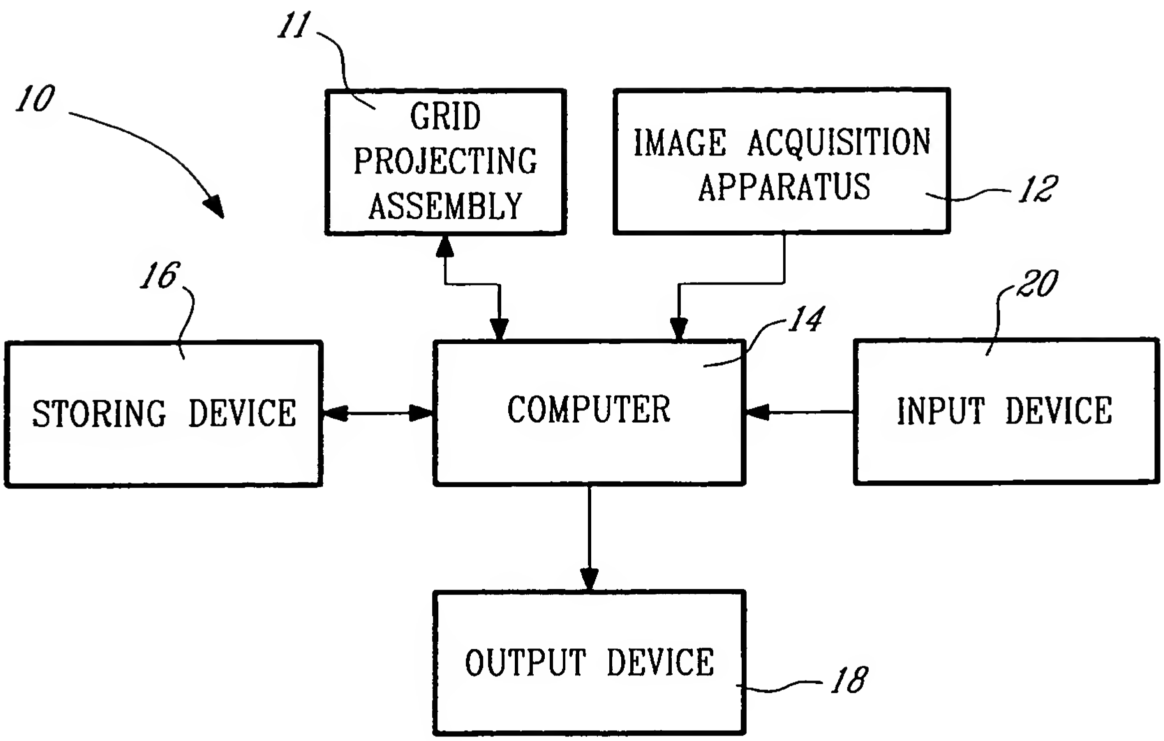

10
11
GRID PROJECTING ASSEMBLY
IMAGE ACQUISITION APPARATUS
12
16
20
14
STORING DEVICE
COMPUTER
INPUT DEVICE
OUTPUT DEVICE
18

FIG. 1

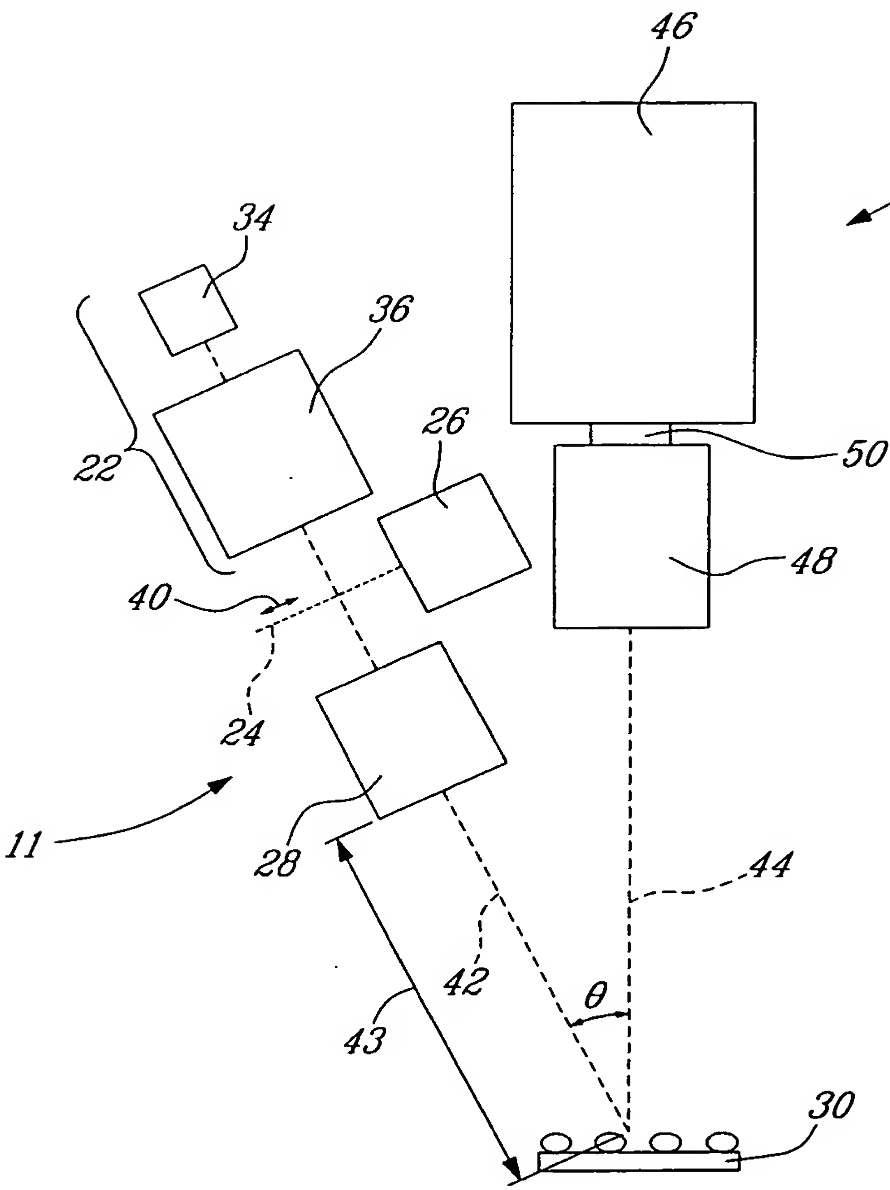
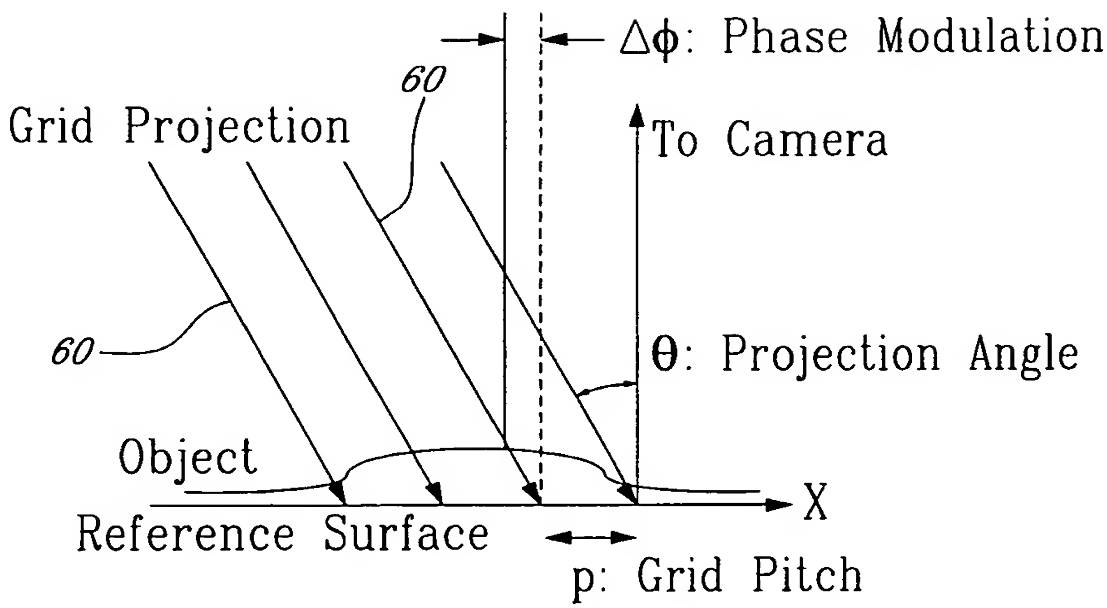


FIG. 2



Δφ: Phase Modulation
60
Grid Projection
To Camera
60
θ: Projection Angle
Object
X
Reference Surface
p: Grid Pitch

FIG. 3

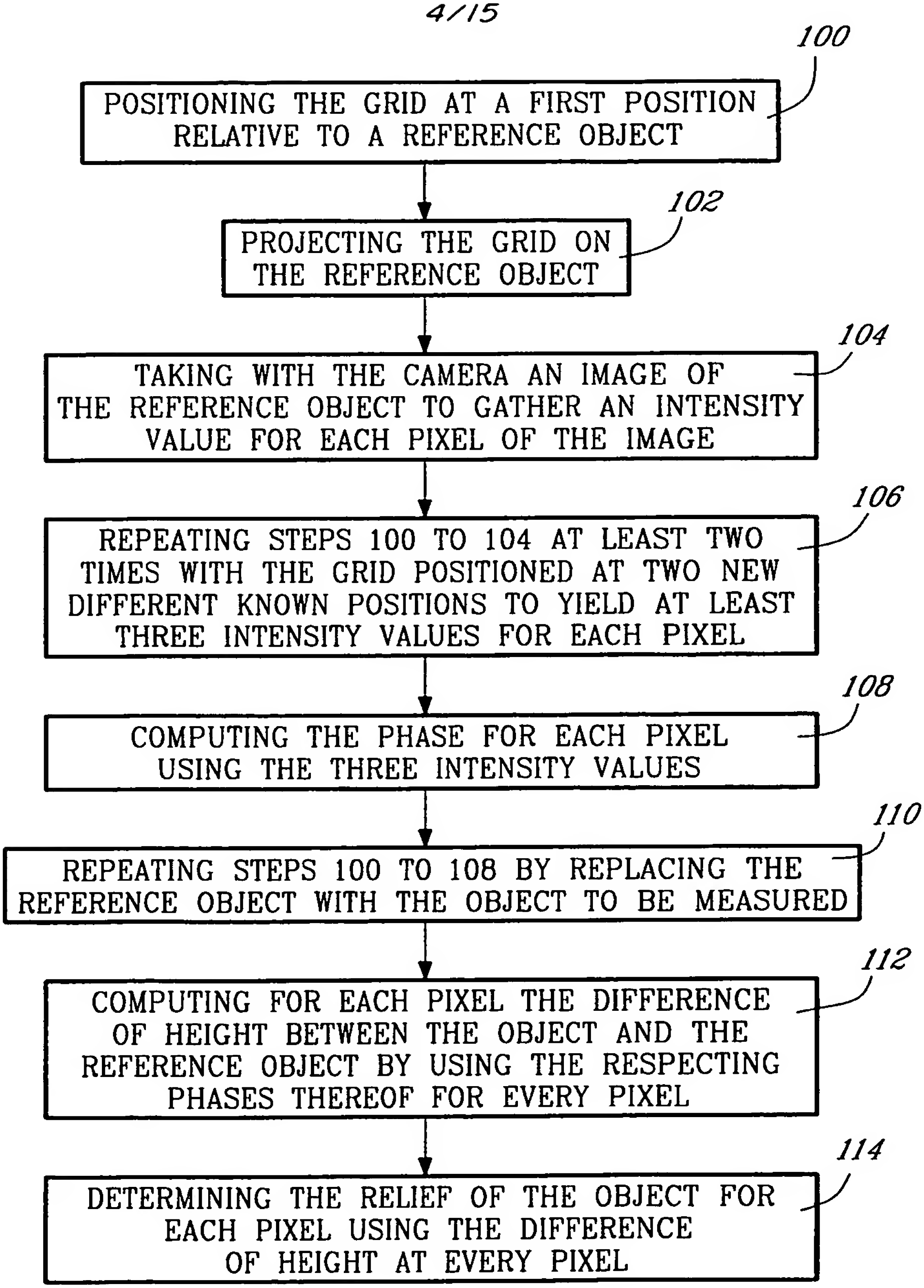

100
POSITIONING THE GRID AT A FIRST POSITION RELATIVE TO A REFERENCE OBJECT
102
PROJECTING THE GRID ON THE REFERENCE OBJECT
104
TAKING WITH THE CAMERA AN IMAGE OF THE REFERENCE OBJECT TO GATHER AN INTENSITY VALUE FOR EACH PIXEL OF THE IMAGE
106
REPEATING STEPS 100 TO 104 AT LEAST TWO TIMES WITH THE GRID POSITIONED AT TWO NEW DIFFERENT KNOWN POSITIONS TO YIELD AT LEAST THREE INTENSITY VALUES FOR EACH PIXEL
108
COMPUTING THE PHASE FOR EACH PIXEL USING THE THREE INTENSITY VALUES
110
REPEATING STEPS 100 TO 108 BY REPLACING THE REFERENCE OBJECT WITH THE OBJECT TO BE MEASURED
112
COMPUTING FOR EACH PIXEL THE DIFFERENCE OF HEIGHT BETWEEN THE OBJECT AND THE REFERENCE OBJECT BY USING THE RESPECTING PHASES THEREOF FOR EVERY PIXEL
114
DETERMINING THE RELIEF OF THE OBJECT FOR EACH PIXEL USING THE DIFFERENCE OF HEIGHT AT EVERY PIXEL

FIG. 4

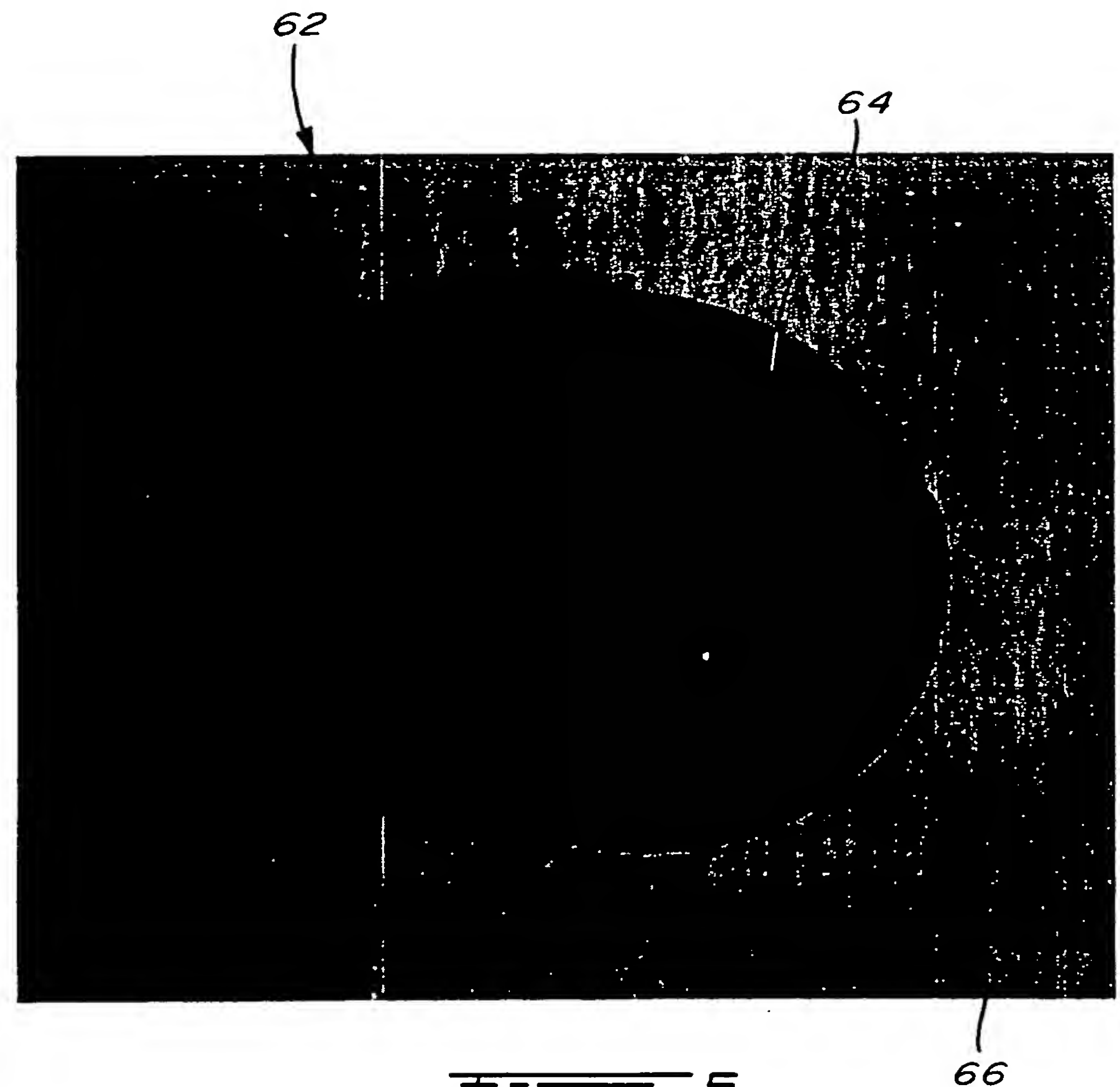


FIG. 5

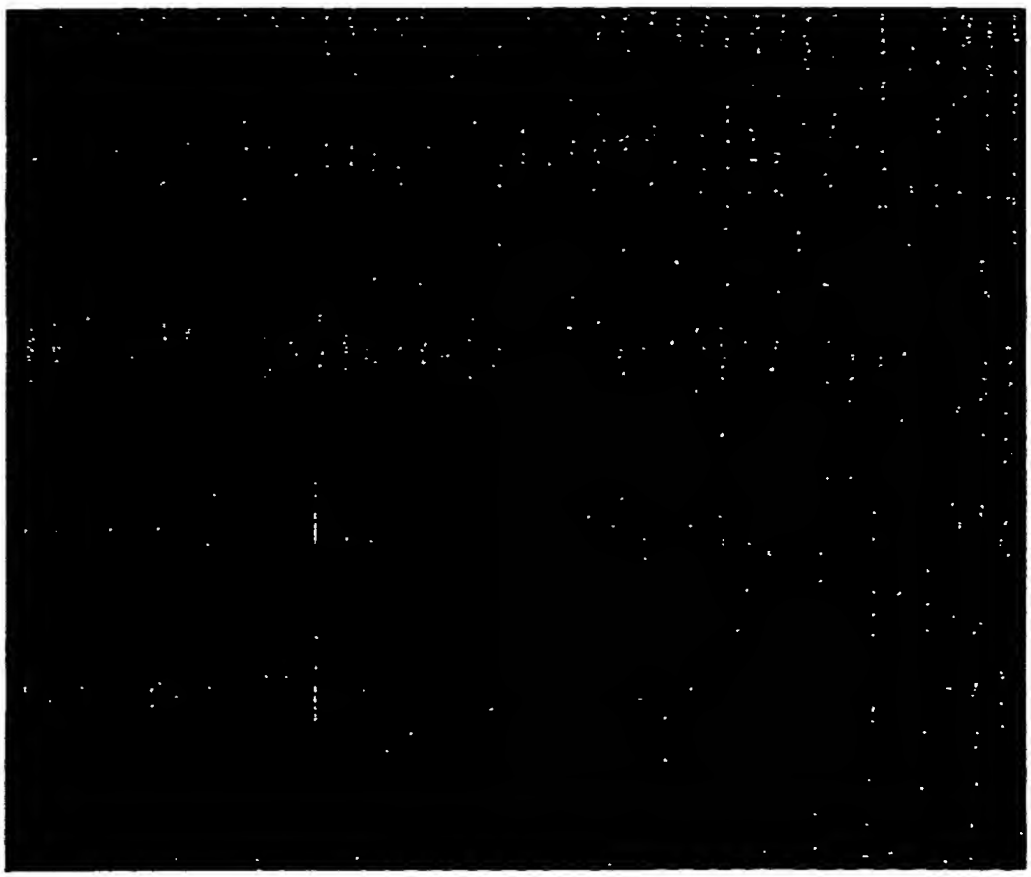


Fig. 6

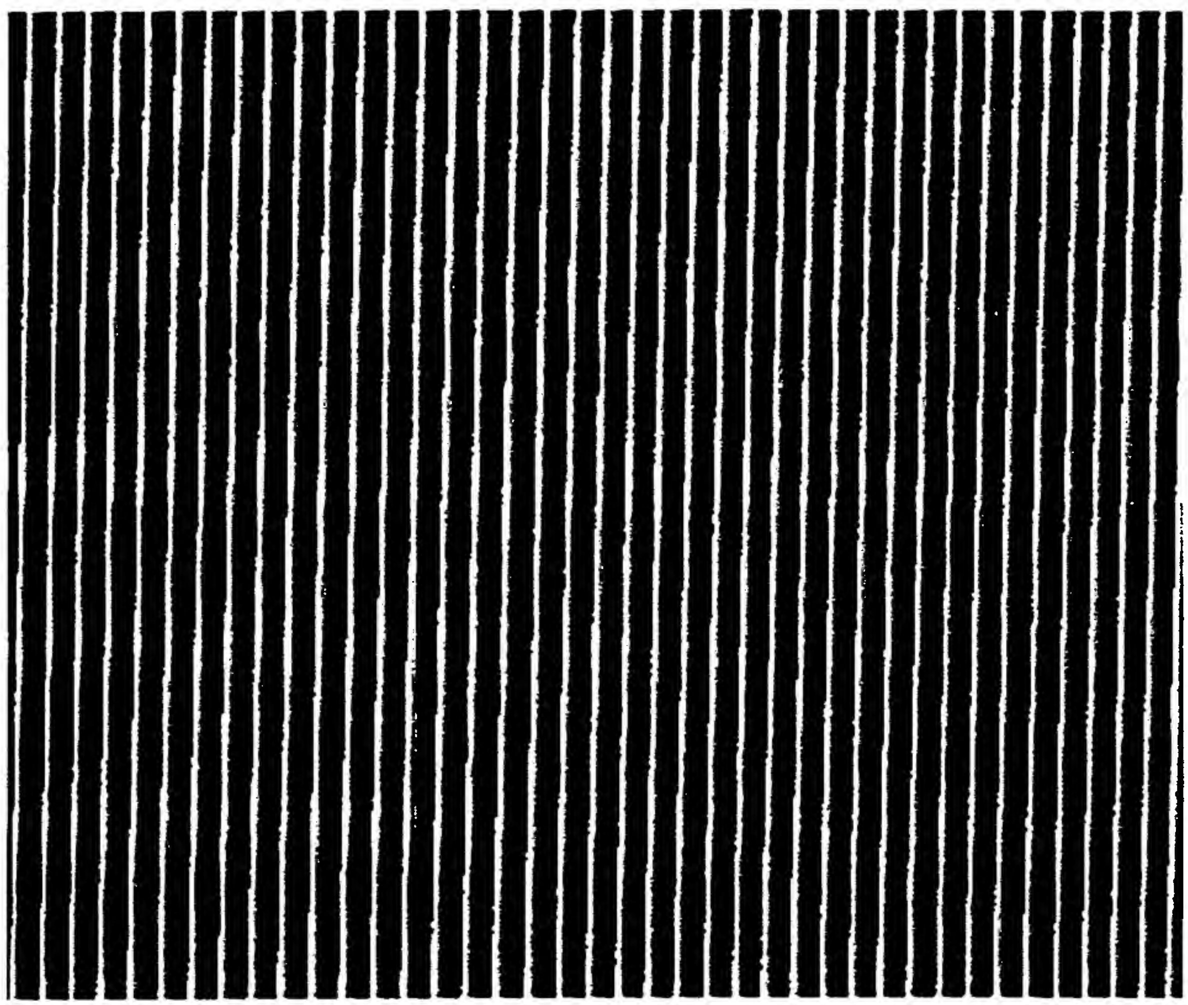


FIG. 7

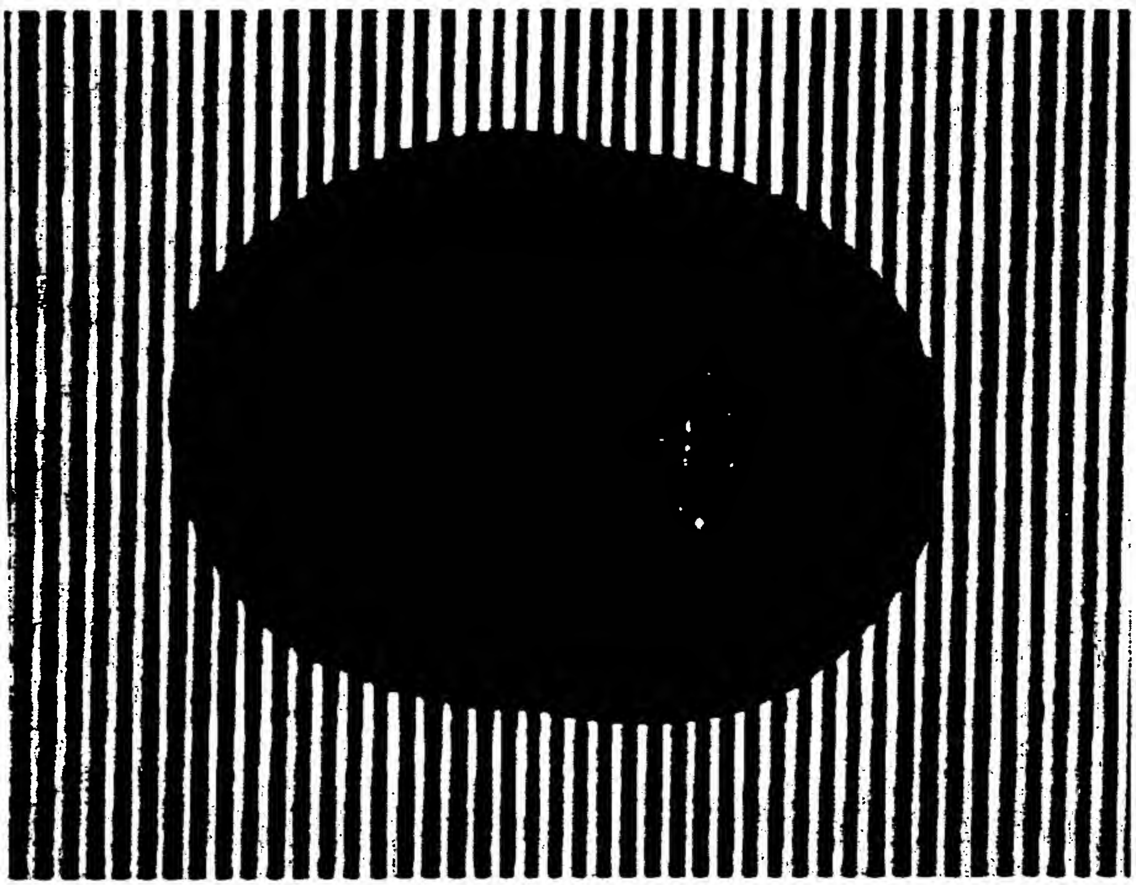


FIG. 8

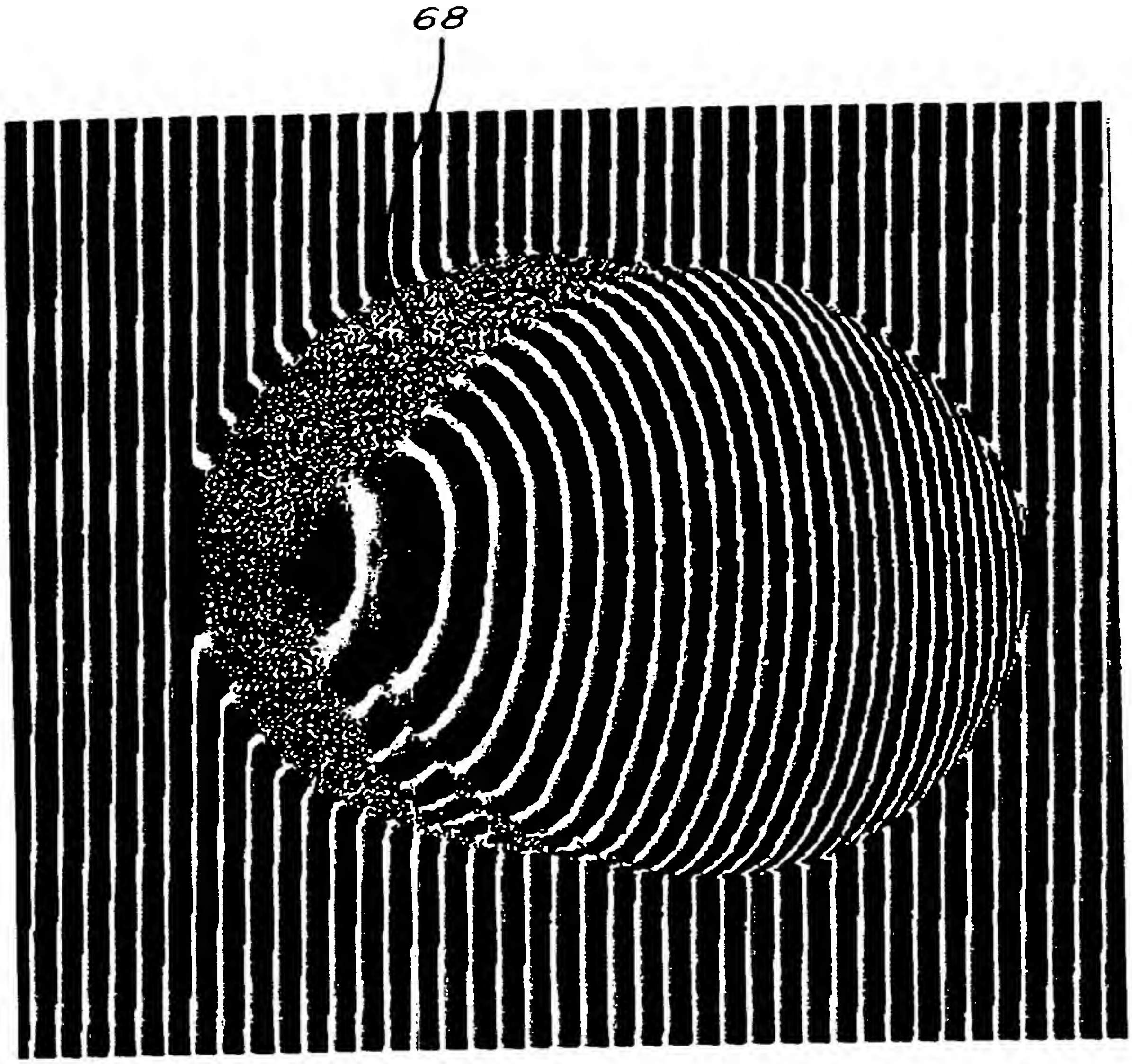


FIG. 9

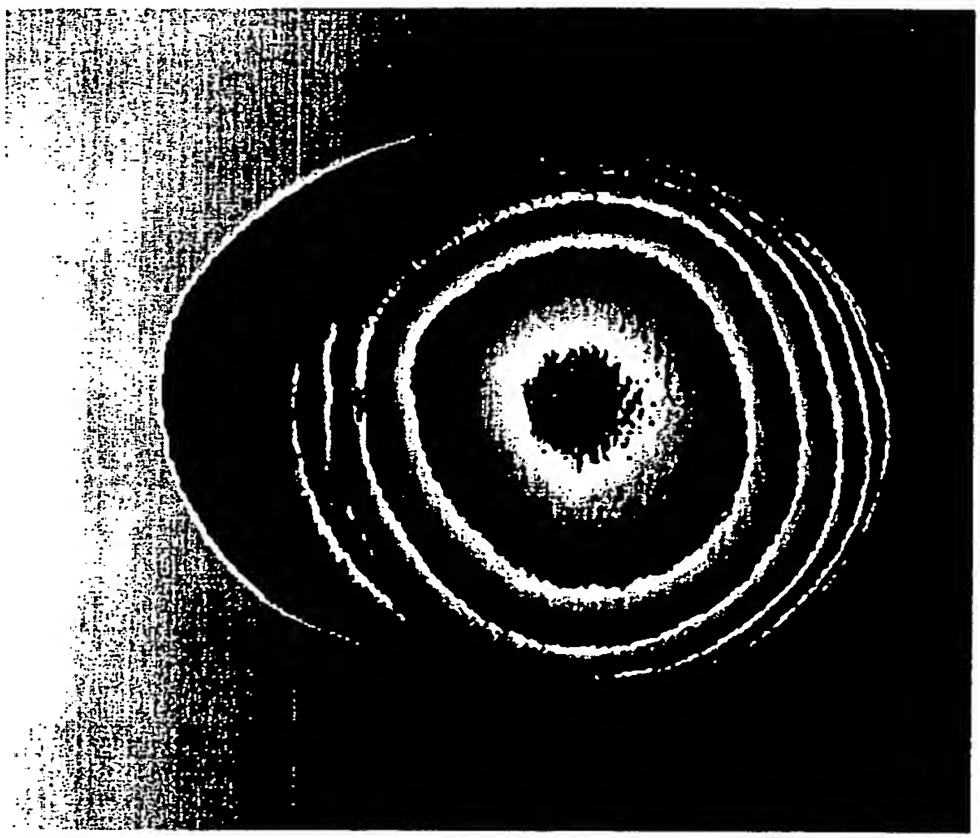


FIG. 10

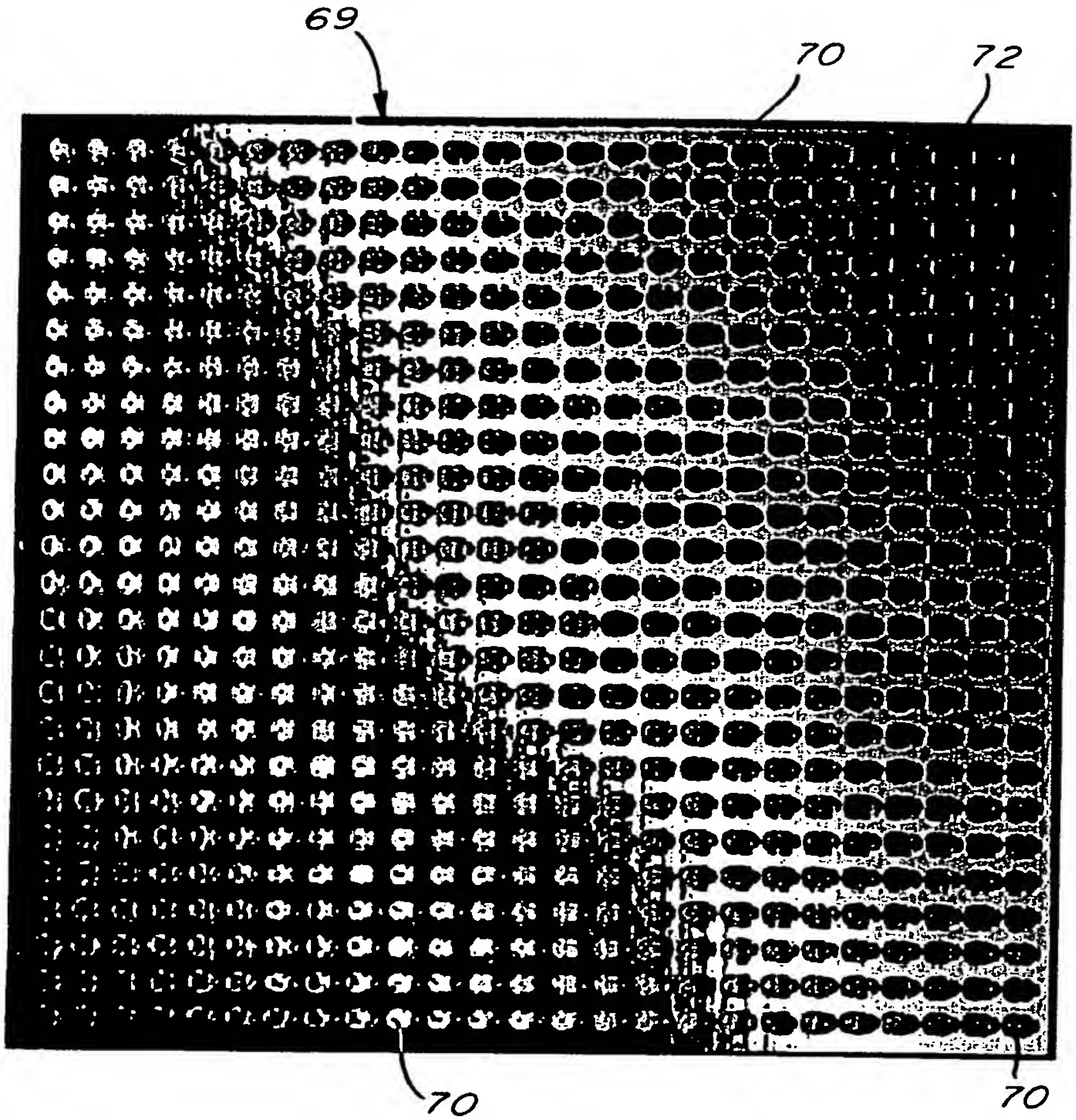


FIG. 11

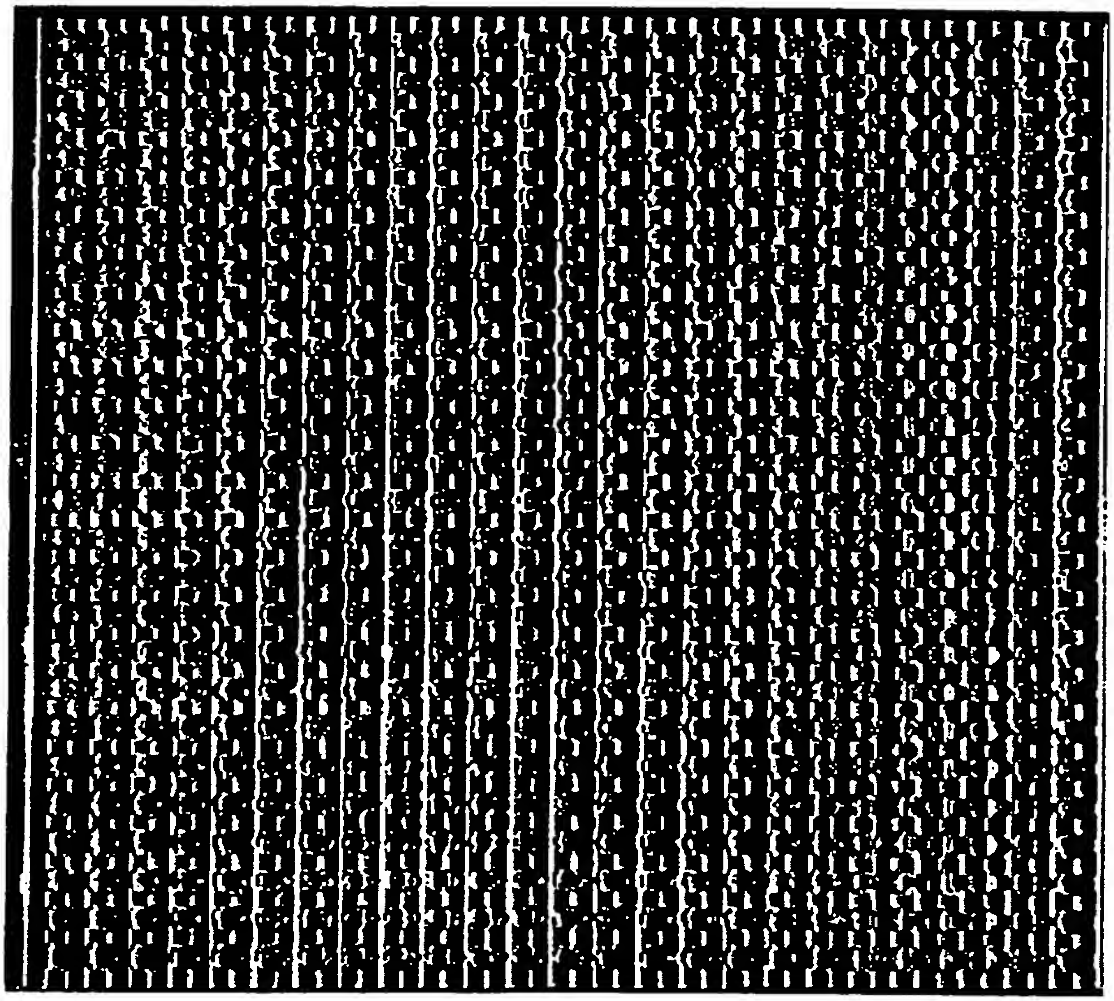


FIG. 12

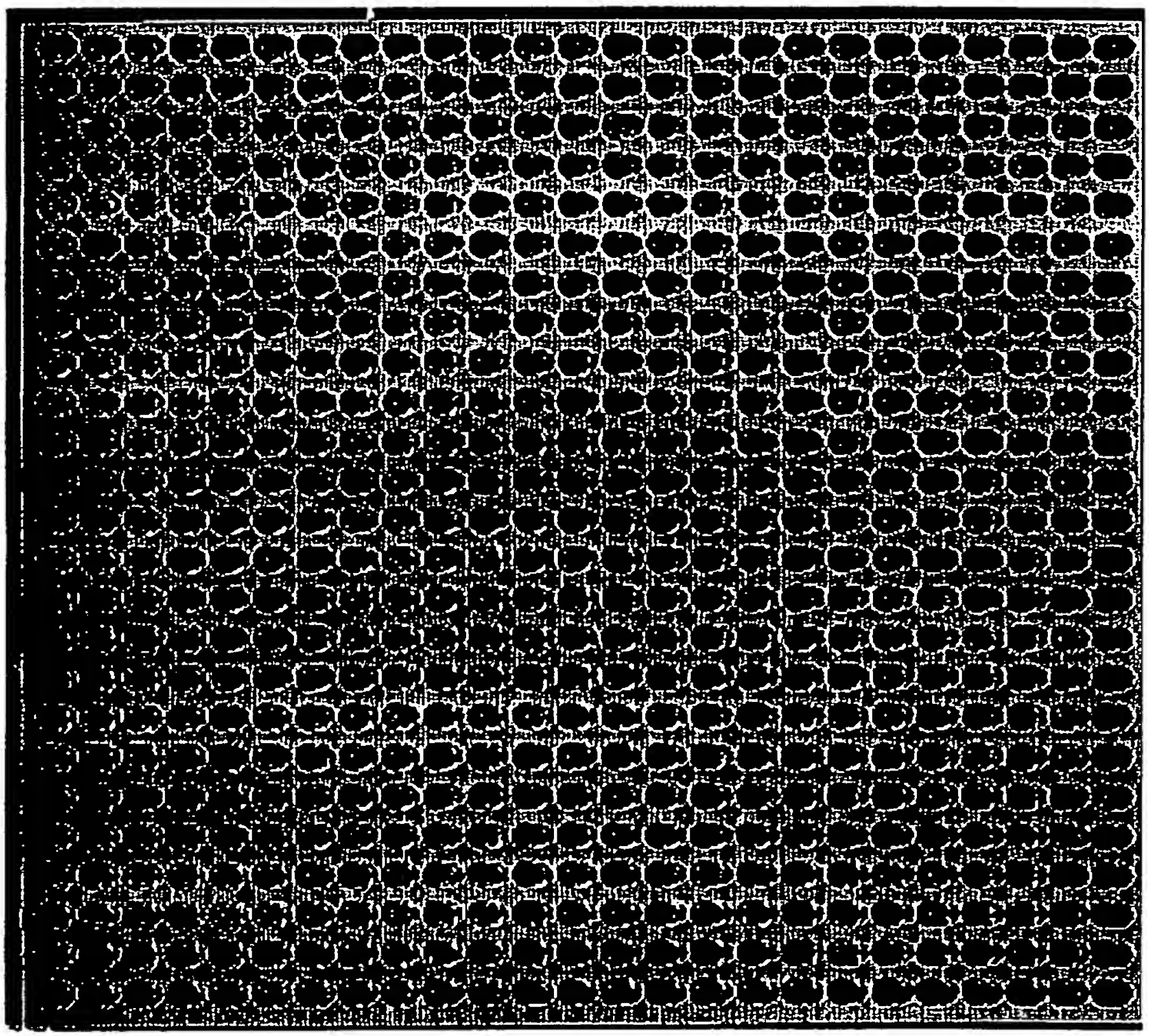


FIG. 13

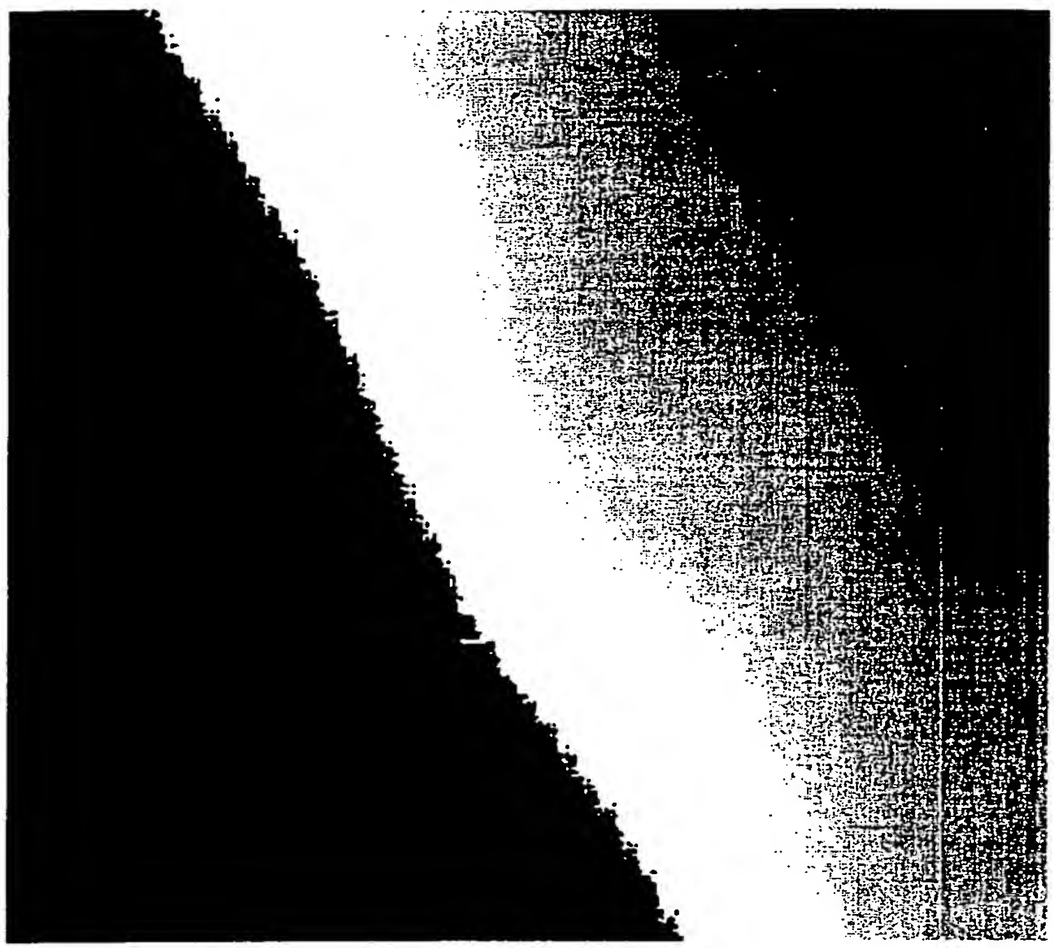


FIG. 14

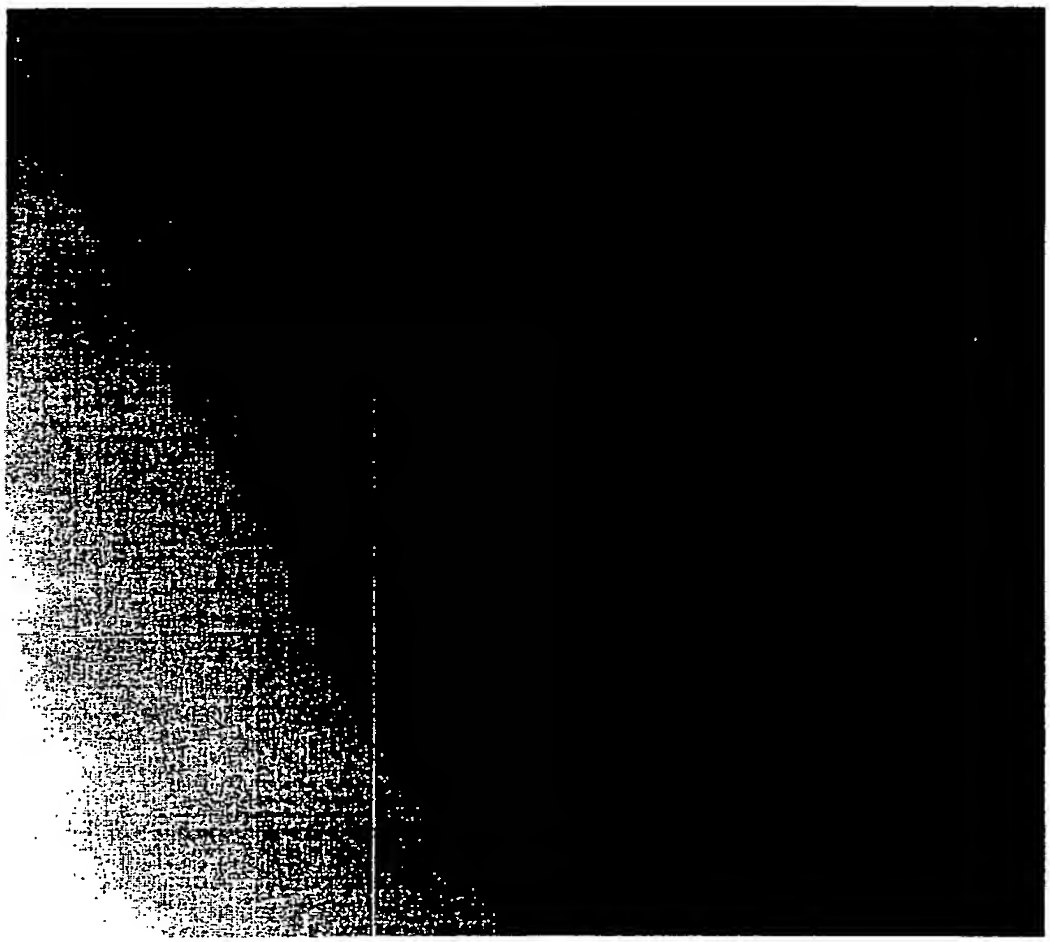


FIG. 15